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CONTENTS

RAISING QUALITY OF PHYSICS EDUCATION: CONTRIBUTION OF JBSE OVER THE PAST ISSUES

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I have worked more than thirty years in physics education (as some of the readers of this journal), many years as a secondary school physics teacher in various curricula (as some of the readers), and more than 20 years at university doing research and preparing future physics teachers (as some of readers). I am also the author of a physics textbook for secondary education, and now I am working on a new one. Naturally, I would like to have the new textbook, like my other outputs, based on the current state of knowledge and well-developed and well-applied theories behind physics education. And here is the seed of the question - how does our journal contribute to raising the quality of our outputs – in my case, increasing the quality of physics education? I first look at the goals of physics education. Here, I use the most straightforward taxonomy of goals presented in (Demkanin 2013): goals related to attitudes of society to science, goals related to methods of science, and goals related to particular knowledge. The last one I split into two sub-goals – knowledge selected to develop methods and attitudes and knowledge selected to raise the quality of living and general scientific culture. Of course, the goals we can reach by means – by the methods of education – methods of teaching and learning. So, let's look at a few previous issues of JBSE and at the contributions having the potential to raise the quality of physics education. I have mentioned only some of the contributions I will probably use in the next few years. I tried to focus on physics education, not explicit chemistry or biology education, even if some of such articles could be fully relevant to my work.

Goals Related to Attitudes of Society to Science

Lamanauskas (2022) emphasised that the natural science literacy of society is insufficient, and its relevance significantly increased in the last decades. In the previous issues of JBSE, we clearly see the importance of environmental education – influencing public opinion about climate change and environmental issues. Lavonen (2022), discussing climate education, highlighted the need for well-educated physics teachers and a new paradigm for preparing physics teachers. Aberšek (2021) discussed the gap between scientists, pseudo-scientists, influencers and politicians, and this gap illustrates the topic of global warming and other ecological issues. Agostinis-Sobrino et al. (2021) discussed health education and lifestyle behaviour, which also could be relevant to changing attitudes to physics education. An interesting term, The Happy Planet Index, is discussed in (Janoušková & Bílek, 2022). Analysis of school textbooks on Physics and other natural science subjects is offered by Revák et al. (2023), who analysed energy awareness education in these books.

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Goals Related to Methods of Science

Wider and Wider (2023) examined students' problem-solving skills and related metacognitive abilities. Taking dimensions such as monitoring, regulation, and evaluation (metacognitive), understanding the problem, devising a plan, carrying about the plan, and looking back, they looked deeply at students' problem-solving skills. As formal education, physics education is rooted in natural science education in primary schools. Lamanauskas (2022) highlighted the need to solve educational problems relevant to primary school pupils, forming their life values. In his research, he found that discussions are not encouraged enough in Lithuania at the level of primary schools. Much more popular are practical activities and demonstrations. Improving science process skills of students with mild intellectual disabilities is examined by Şenel Çoruhlu et al. (2023).

Goals Related to Knowledge Selected for the Development of Methods and Attitudes

I am sure we have some articles dealing with physics knowledge selected for school courses to develop science process skills and attitudes to science, but I did not find anything explicit in the past issues. One more, this does not mean that we do not have such articles. Some readers can argue that everything we teach is developing methods of science and attitudes.

Goals Related to Knowledge Selected to Raise the Quality of Living and General Scientific Culture

The concept of inertia, an essential topic of mechanics, with some critical notes from the history of this topic, is discussed by Bussotti (2021). Alternative conceptions of students in Newtonian mechanics are examined by Bahtaji (2023). Learning heat and temperature concepts by pupils at primary schools are discussed by Tseng et al. (2023).

Teaching Physics

In the context of climate education, Lavonen (2022) highlighted the relevance of project-based teaching methods, guiding students to ask relevant questions related to the complex phenomenon, critically search for information, participatory approaches, and affect-driven approaches. Alp and Coskun Onan (2023) analysed the possibilities for using comics to constitute climate change awareness in 5th grade. Aberšek (2021) highlighted, in the context of science versus pseudo-science, the development of critical thinking and strategic separation of truth (ideas based on science) from potential lies (alternative ideas contrary to scientific ideas, myths). The development of the physics module applying categories such as personal interest, sense-making, and effort is discussed by Sulaiman et al. (2023). The difference between end-of-chapter problems and inquiry activities used as homework was investigated by Simić et al. (2023), who found that simulation-based and video-based homework contributes to the improvement of conceptual understanding in mechanics. The role of multimedia (simulations, animations, videos, models) in teaching university students black body radiation, photoelectric effect and other quantum physics topics is discussed by Nyirahabimana et al. (2023). Interesting factors related to the social responsibility of scientists and engineers, as viewed by pre-service physics teachers, are analysed by Zhang (2023). The typology of questions used by science teachers is examined by Saka and Inaltekin (2023).

Learning Physics

Illustrated on science teacher education, Feser (2021) discusses the topic related to future science teacher learning, the topic of belonging to science. How do physics teachers feel as an integral part of the physics community? How do physics researchers feel physics teachers belong to the physics community? Secondary school students' perception of the science learning environment, especially metacognition and self-efficacy, is analysed by Kim and Alghamdi (2023). A construal level theory, which includes the term psychological distance, illustrates environmental issues Aberšek (2022). Toulmin's argument pattern and its impact on the learning of lower secondary school pupils in the context of the solar system, force and motion, and systems in the human body were analysed by Acar and Azakli (2023). They report that using this argument pattern raised pupils' metacognition and logical thinking. The effect of a particular combination of home and classroom activities encouraging students

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to take more responsibility for their learning is examined in the context of direct electric current topics Radulović et al. (2023). Physics teachers' learning how to use research papers to creatively develop teaching sequences of a particular quality (based on the information from the research papers) was studied by (Park, Yoon, Lee, 2023). Our journal, as well as general physics education, includes the education of students with mild intellectual disabilities. Improving their science process skills was examined by Şenel Çoruhlu et al. (2023).

Contribution to the Raising Quality of Future Physics Education

Empirical research well set to a theoretical background, without doubt, is much better than empirical research based only on the intuition of a person with limited experience. Even if I have more than 30 years of experience with secondary school students and university students – students in pre-service studies, in-service courses and students of hard science, I still feel a need to cultivate my theoretical background. One type of activity related to this need is looking at JBSE articles, letting them go through the filter of my previous experiences and theoretical knowledge, allowing them to resonate, interfere, constructively or destructively. It is quite a pleasant experience to identify a myth I have used as a truth for years. Similarly, it is a pleasant experience to see that some groups of people thousands of kilometres from my hometown, Bratislava, think likewise and believe in the same principles and tenets of physics education as I use in my research and teaching practice.

Physics, Physics Education, and the Theory of Physics Education are often considered quite old science disciplines. Some say that the roots are in Newton's Principia (Newton's laws are probably in every physics textbook), some say that even Archimedes was important in the development of Physics (Archimedes' principle is perhaps in every physics textbook), methods of education applied to teaching Newton's laws and Archimedes principle are probably in every course on didactics of physics. Where to go in raising the quality of physics education? Better selection of physics topics taught in schools – to cultivate attitudes of society, better use of new digital technologies – to cultivate the abilities to use methods of science? Let me be less abstract – let's look at concrete material – water/ice and graph its density versus temperature (in stable states), Figure 1, and detail in Figure 2.

Figure 1
Density-Temperature Graph for Illustration of Context

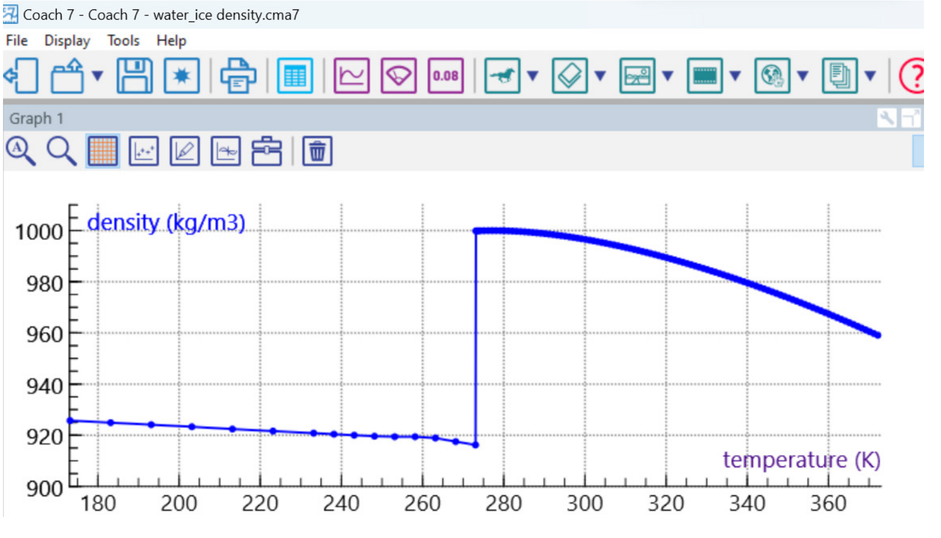

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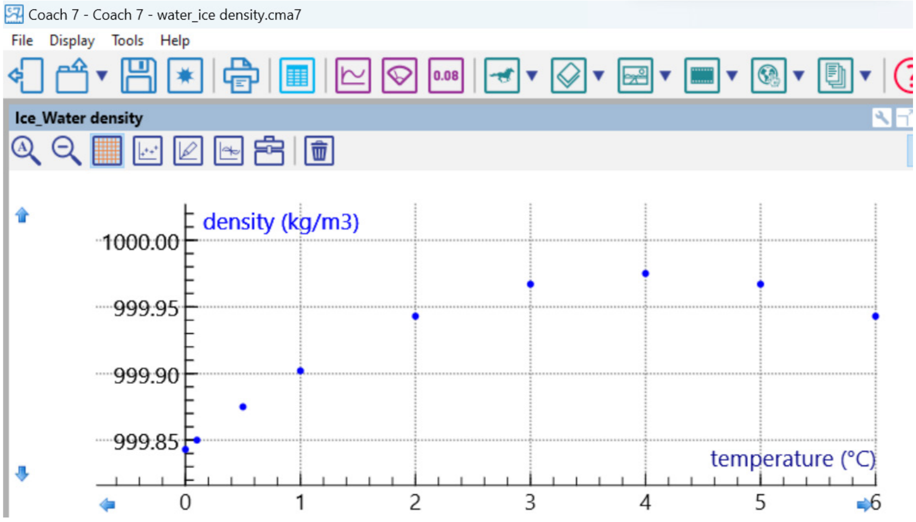
Figure 2
Interesting Detail on the Density-Temperature Graph, Note the Unit of Temperature Used



What to teach and how to teach about water and ice? How can we raise the quality of using contexts related to water and ice in physics education? And how to teach? And how do our students learn?

One way that naturally emerged in the last decades could be based on the application of new knowledge in neurosciences, in the science of mind-brain-education. Similarly, as physics education was influenced by researchers such as Piaget, Maslow, and Bruner in the second half of the 20th century, nowadays, we can try to incorporate into our efforts the results of research of groups focusing on possibilities of applying knowledge based on new opportunities of brain scanning, artificial intelligence. Besides articles published in JBSE, I often look at some books and can recommend one here. Tokuhama-Espinosa (2021), in her book *Bringing the Neuroscience of Learning to Online Teaching*, brings many ideas applicable to the theoretical backgrounds of our articles related to improving physics education in the near future.

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MICROBIOLOGICAL AWARENESS AMONG UPPER-SECONDARY SCHOOL STUDENTS IN THE CONTEXT OF COVID-19 VACCINATION

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Abstract. *There is evidence that education levels have an impact on people's attitudes toward vaccination. The recent COVID-19 pandemic has highlighted the need to maximize vaccinations - one of the most efficient ways to prevent the spread of infectious diseases. Young individuals play a major role in disease transmission due to their intense social life and frequent asymptomatic infections. In this study, a survey of upper secondary school students in Poland was conducted to assess their microbiological awareness depending on subjects that they studied on the extended level and COVID-19 vaccination willingness. Participants learning biology and chemistry on the extended level had significantly higher microbiological awareness. Clear proof of microbiological awareness's influence on vaccination willingness was not found. Although studying biology did not significantly influence students' willingness to be vaccinated, their place of residence did. Students from bigger cities were more willing to get vaccinated. These results show that while science education raises microbiological awareness among upper secondary school students, place of residence, likely through social pressure, is a more important factor influencing vaccination willingness. It is suggested that more effort should be put into educating society as a whole and encouraging vaccination particularly.*

Keywords: *attitudes towards vaccinations, infectious diseases, microbiological education, SARS-CoV-2, upper secondary school students*

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Introduction

Vaccination is one of the most efficient and cost-effective procedures for preventing hospitalization and death from diseases, including COVID-19. Vaccines also play a major role in preventing the transmission of the disease and a modest one in the case of COVID-19 (Kraaijeveld, 2022). Although children and adolescents are less liable to the severe cause of this disease and less likely to die as a result of it (Viner et al., 2021), researchers emphasize the high value of vaccinating young people as they can transmit the infection to people at high risk - the elderly or chronically ill. Especially if one considers that young people lead a more intense social life and thus come into contact with more people - including potential carriers of the disease (Zimet et al., 2020).

The 2009 experience of the influenza epidemic (H1N1 virus) shows that societies are reluctant to vaccination - rates of vaccination-friendly attitudes in individual countries ranged from 17% to 67% (Al-Mistarehi et al., 2021). The more recent pandemic of COVID-19 seems to have demonstrated a similar tendency when the general public's cold reception of the developed vaccines challenged public health. Interestingly, data on attitudes toward vaccination among adults indicate that a higher level of education correlates with a more favorable attitude toward vaccination (Al-Mistarehi et al., 2021; Afifi et al., 2021; Lin et al., 2020), which is also true in Poland as demonstrated by Gołębiowska et al. (2023), and Raciborski et al. (2021). Moreover, the stream of studies also influences the decision whether to get vaccinated or not. For example, Šorgo et al. (2022) demonstrated that Slovenian medical students are more inclined to get vaccinated against COVID-19 than their peers who study different fields, including health care related subjects.

Nevertheless, education is not the only factor that impacts vaccination willingness in adults. Other factors such as place of residence (Raciborski et al., 2021; Gołębiowska et al., 2023), lifestyle (Fazel et al., 2021), and being a medical practitioner (Wang et al., 2020) have also been proven to influence

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the attitude towards vaccinating. It has been found that medical students favor vaccination more than their peers who attend non-medical degree courses. According to an analysis carried out by Khubchandani et al. (2022) in 39 countries, COVID-19 vaccinations are strongly rejected by an average of 18.9% of medical students and as many as 22% of non-medical students.

To date, few studies have examined a big population of adolescents in the context of their vaccination willingness. In Austria, the impact of the type of school was studied - it was shown that students of general upper secondary schools are much more favorable to vaccination than those participating in vocational education (53% of applicants and an indicator of 4/5 points vs. 28% of applicants and an indicator of 3.16 / 5 points - where 5 is "I definitely want to get vaccinated" and 1 is "I definitely don't want to get vaccinated" (Humer et al., 2021)). Other questionnaires conducted among adolescents from different countries indicate that slightly more than half of the respondents declare the willingness to be vaccinated, for example:

- in the USA, age 12-17: 64% (26.1% vaccinated, 38.2% willing to get vaccinated) (Scherer et al., 2021);
- Canada, age 16-21: 65.4% (Afifi et al., 2021).
- Austria, upper secondary schools 53% (Al-Mistarehi et al., 2021);

Research from Great Britain shows that the older the students, the more they favor vaccination, and fewer are hesitant. On the other hand, the percentage of opponents is relatively constant (Fazel et al., 2021).

When examining education as a factor influencing vaccination willingness, one should also consider significant changes in the Polish education system, which happened several times in the last 20 years. The extensive structural reform of 1999 increased the autonomy of the schools and teachers, introduced standardized testing, but most importantly, cut the primary school from 8 to 6 years and established lower secondary schools (called gymnasiums) that children were obliged to attend before upper secondary school (Jakubowski, 2020; Wiśniewski & Zahorska, 2020). The reform led to a significant improvement in Polish students' PISA performance. The average Polish student's results have improved by over 30 points in reading since 2000 and by about 25 points in mathematics since 2003. Poland experienced the most considerable improvement from 2000 to 2018 among the OECD countries (Jakubowski, 2020). Despite that, in 2017, another major structural reform that canceled lower secondary schools was introduced. The reform was rapidly implemented without much thought, preparation, or consultation with the teachers in the name of 'the good old days' (Wiśniewski & Zahorska, 2020). It is important to note that the most recent PISA results are from 2018 and therefore are a product of children educated in a system introduced by the 1999 reform.

Vaccination willingness was also studied in the light of one other factor than education level among school children. The influence of the socioeconomic situation (including migration history) and gender was established on the students' approach and their guardians' (Humer et al., 2021; Scherer et al., 2021).

Research Problem

It is expected that education has a major influence on attitudes toward vaccination. However, there are no studies on schoolchildren that would directly link the scope of their biological knowledge with the willingness to vaccinate against COVID-19. The relationship, or lack thereof, is especially interesting since most conventional schools mainly focus on transferring and examining general theoretical knowledge.

Furthermore, the influence of other factors (place of residence, lifestyle, and close acquaintance with a medical practitioner) on willingness to vaccinate against COVID-19 was never studied in upper secondary school students in Poland. Even though in the research performed by Gołębiowska et al. (2023) some representatives of this group were probably present, they constituted less than 2.5% of the studied population and their answers were not analyzed separately.

Research Aim

The aim of the present research was to determine whether class profile, place of residence, lifestyle, and close acquaintance with a medical professional influence microbiological awareness and the decision to get vaccinated against COVID-19 among high school students. A question of whether the level of microbiological awareness impacts one's willingness to be vaccinated against COVID-19 was also addressed. In this case, microbiological awareness was understood as basic and strictly pragmatic microbiology knowledge that a Polish high school attendee should possess according to the official curriculum. The study was conducted in Poland, and, in this

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context, it is important to note that in the Polish education system, high school students can learn each subject on two levels - basic and extended. The basic level is more pragmatic and obligatory for all students, while the extended is optional and is meant to prepare students for an extended level exam considering a particular subject (The Ministry of National Education, 2018). Consequently, it was presumed that learning a subject in an extended scope could affect microbiological awareness.

Research Methodology

General Background

A survey strategy was implemented for this research with the use of an online questionnaire (Table S1). The questionnaire aimed to gather information about microbiological awareness of students and their vaccination willingness. The answers were collected between November 2021 and April 2022 from students attending upper secondary schools across Poland.

Participants

The questionnaire was shared on social media. However, only several students submitted their answers. It was decided to recruit participants by emailing information about the possible study enrollment to the principal's office. The authors' Python script was used to send the emails to all high schools located in 6 voivodeships (Masovian, Greater Poland, Warmian-Masurian, Silesian, and Podlaskie) listed in the Polish Registry of Schools and Educational Facilities (https://rspo.gov.pl/). Unfortunately, only some headmasters agreed and expressed the will for their students to participate. All of the schools who agreed were enrolled in the study.

Consequently, the questionnaire was filled by 1215 respondents from 6 abovementioned voivodeships: 3 schools from Masovian, 1 school from Greater Poland, 1 school from Warmian-Masurian, 2 schools from Silesian, and 2 schools from Podlaskie. These voivodeships create a nearly diagonal section through Poland. Therefore, the data were recognized to be fairly representative. However, low responsiveness of schools prevented the authors from obtaining more answers.

In further analysis, 1170 responses were considered. 45 responses were not taken into account due to (a) imperfection of the constructed questionnaire - problems with grading the answer "I don't know this rule" in question 7 - see Supplementary Table 1 (43 responses), (b) vulgar answers in open questions indicating that the participant did not take the questionnaire seriously (2 responses).

The considered respondents declared to study varied subjects on the extended level: 693 of them studied biology on the extended level, 605 - chemistry, 528 - foreign language, 394 - mathematics, 235 - Polish, 190 - history, 148 - social sciences ("wiedza o społeczeństwie"), 147 - geography, 124 - physics. 888 respondents declared to be vaccinated against COVID-19, 59 were not but planned to be in the future, 123 were not vaccinated and were hesitant to get the vaccination, 100 were not vaccinated and refused ever to be vaccinated against COVID-19.

Instrument and Procedures

An online questionnaire (Table S1) in Google Forms was designed. The questionnaire consisted of a contextual part and a cognitive part. In the contextual part, students were asked about their grade, place of residence, and if one or more of their family members have work experience in medicinal sciences (e.g., is/was a doctor, nurse, technician, etc.). Participants were also asked about extended subjects and preferred ways of spending free time. Based on this question, students were assigned to one of four groups: physically active, socially active, physically and socially active, or inactive.

The cognitive part focused on knowledge of microbiology. Respondents answered questions about basic microbiological knowledge, infectious disease prevention, and attitude towards vaccination against COVID-19. All questions in the cognitive part were constructed based on the Polish biology curriculum (Table S2), ensuring their validity. Questions and their aim are explained in Table S1.

Participants earned points for correct answers in the microbiological awareness part of the questionnaire. The maximum number of points in each question was equal to the number of correct answers in that question. In questions in which more than one answer was correct, points were subtracted for each incorrect answer, and the

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minimum number of points participants could earn for those questions was zero. It was assumed that the number of earned points was proportional to the microbiological awareness of the participants.

The consent for students' participation in the study was sought with the school's headmaster. The principal was informed about the aims of the study in detail and was given an opportunity to examine the questionnaire. Afterwards, the questionnaire was sent by the headmaster electronically to the students. Participation in the survey was voluntary. The questionnaire contained information about the aims of the study so the students' consent to participate was informed. Participants could quit the study at any moment. No headmasters nor teachers had access to the results of the survey. The questionnaire did not collect personal data as understood in the General Data Protection Regulation (Regulation (EU) 2016/679) nor the information about the school to which a participant attended.

Reliability of the Instrument

The reliability of the cognitive part was assessed by calculating the ω coefficient, which was proved to be the most reliable (Zinbarg et al., 2005). Corrected item-total correlations (Cureton, 1966; v2.3.6; Revelle, 2023) and discrimination indexes (biserial point correlations) were also calculated for each question. To assess the difficulty of tasks, response frequency scores (defined as the mean score divided by the maximum possible score) were calculated (Brzezińska, 2020).

The calculated ω coefficients equaled: ω hierarchical = .44, ω total = .59, and ω hierarchical asymptotic = .75. It was decided that the asymptotic version of the ω hierarchical coefficient will be considered because it produces the least biased results of general factor reliability (Trizano-Hermosilla et al., 2021). Consequently, it was concluded that the reliability of the test was satisfactory.

The corrected item-total correlations exceeded .2 for all tasks, showing their acceptable consistency with the rest of the instrument (Collins et al., 2010). The discrimination index of five questions was higher than .4, indicating good discrimination. For three other tasks, the discrimination index was above .2, which was qualified as fairly discriminating (McGahee & Ball, 2009). Question 2 was recognized as a task of the lowest quality showing a discrimination index lower than .2 and a corrected item correlation of .206. However, this question referred to an important topic of human symbiotic microbiota. Consequently, it was decided not to remove it from the analysis.

Question 2 was also recognized as the easiest task, with a response frequency score of .979. On the contrary, Question 3 was considered the hardest. Results for all items analyzed are presented in Table 1.

Table 1
Results of the Quality Analysis for Each Question Asked In the Cognitive Part of the Questionnaire

Question	Corrected item total correlation	Discrimination index	Response frequency score
Question 1	.412	.515	.385
Question 2	.206	.187	.979
Question 3	.504	.733	.274
Question 4	.366	.565	.524
Question 5	.284	.505	.516
Question 6	.250	.241	.910
Question 7	.253	.266	.864
Question 8	.356	.443	.423
Question 9	.295	.367	.315

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Data Analysis

Most of the respondents chose more than one extended subject. Consequently, to determine the influence of participants' chosen extended subject on microbiological awareness, groups of respondents that chose a particular extended subject and all participants that did not were compared. This analysis was conducted for the following extended subjects: social studies, foreign language, Polish language, mathematics, history, geography, physics, chemistry, and biology. Microbiological awareness of participants who were related to a medical worker and those who were not were compared. Respondents who answered "I don't know" in the questionnaire were grouped with those who answered "No." It was assumed that since the participants do not know if their relatives work in the medical field, it would not significantly affect them. For all groups of data Shapiro-Wilk's normality tests were conducted. In all cases, data could not be approximated by the normal distribution.

Consequently, the Kruskal-Wallis test was used. Effect sizes were measured by calculating the ε^2 coefficient for data showing statistically significant differences. Means (*M*) and standard deviations (*SD*) of obtained points within groups were calculated.

Microbiological awareness differences depending on the place of living were studied. Because of the low number of participants living in cities ranging from 50,000 to 150,000 citizens and 150,000 to 500,000 citizens, they were grouped into a single category of cities ranging from 50,000 to 500,000 citizens. Four groups of results were obtained: participants who lived in villages, towns smaller than 50,000 citizens, cities ranging from 50,000 to 500,000 citizens, and cities larger than 500,000 citizens. Microbiological awareness differences were examined depending on participants' vaccination and physical activity decisions. Based on the answers about their physical activity, participants were grouped into four categories:

a) Physically and socially active (spend time both on sports and activities with friends and family),
b) Physically active (spend time on sports, but not on activities with friends and family),
c) Socially active (spend time on activities with friends and family, but not on sports),
d) Not active (do not spend time on sports or activities with friends and family)

For this analysis, the Kruskal-Wallis test was used. If the differences between groups were statistically significant, post-hoc Dunn's test was performed. Means (*M*) and standard deviations (*SD*) of obtained points within groups were calculated.

It was studied if willingness to vaccinate depends on the place of living. Two groups were distinguished: participants living in villages and towns of less than 50,000 inhabitants and from cities of more than 50,000 citizens. It was also examined if willingness to vaccinate depends on physical activity (groups a, b, and c were merged) and close relationships with medical workers. Chi-squared tests were conducted, including described categories and participants' willingness to vaccinate. Theoretical distributions were calculated for the datasets in which differences were statistically significant. Effect sizes were measured by calculating the φ coefficient for data showing statistically significant differences.

Statistical analysis was conducted using the R software (R Core Team, 2013), dunn. test package (Dinno & Dinno, 2017), psych package (v2.3.6; Revelle, 2023), and rcompanion package (v2.4.30; Mangiafico, 2023) according to the procedures described. Statistical significance at $p < .05$ was assumed. ε^2 Values were interpreted as follows: $\varepsilon^2 > .14$ = strong effect, $.14 > \varepsilon^2 > .06$ = medium effect, $.06 > \varepsilon^2 > .01$ = weak effect, $\varepsilon^2 < .01$ = no effect (Khalilzadeh & Tasci, 2017). φ Coefficient values were interpreted as follows: $\varphi > .5$ = strong effect, $.5 > \varphi > .3$ = medium effect, $.3 > \varphi > .1$ = weak effect, $\varphi < .1$ = no effect (Cohen, 1977).

Research Results

Microbiological Awareness

On average, the respondents scored 8.5 points (out of 17 points possible in the test) with a standard deviation of $SD = 2.7$. The maximum score obtained was 16. The minimum score obtained equaled 0. The frequency distribution of all scores is presented in Figure 1.

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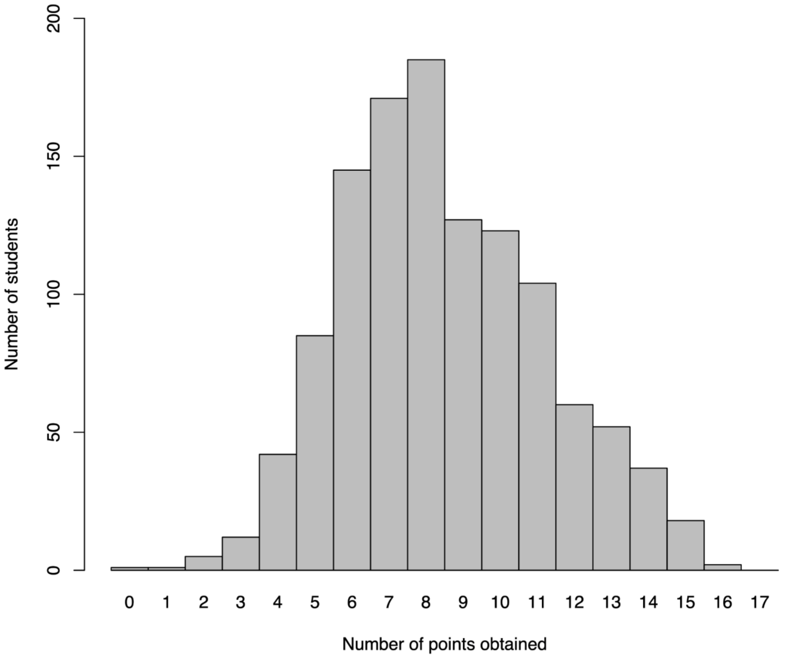
Figure 1
Histogram of Number of Points Obtained In the Knowledge Test



Note. The height of a bar indicates the number of students who obtained a particular number of points in the cognitive part of the questionnaire.

Extended subjects that had a moderate positive influence on microbiological awareness were biology ($p < .001$, $\varepsilon^2 = .0837$) and chemistry ($p < .001$, $\varepsilon^2 = .0912$). It should be mentioned that only 11 people studying chemistry did not study biology at the extended level. Therefore, it was impossible to examine the influence of studying chemistry without the obvious influence of studying biology simultaneously. Mathematics, without excluding individuals studying biology on the extended level, seemed to also have a positive impact ($p = .003$). However, the ε^2 value of .0072 indicated no significant effect.

Extended subjects that had a weak negative influence on microbiological awareness were geography ($p < .001$, $\varepsilon^2 = .0239$), history ($p < .001$, $\varepsilon^2 = .0207$), Polish ($p < .001$, $\varepsilon^2 = .0234$), social studies ($p < .001$, $\varepsilon^2 = .0227$) and mathematics when individuals studying biology were excluded ($p < .001$, $\varepsilon^2 = .0148$). Studying physics also seemed to impact microbiological awareness negatively ($p = .006$); however, a low ε^2 (.0064) indicated no effect.

In the case of foreign languages, no significant differences were detected in the total sum of points scored on the test in the case of people who studied this subject and those who did not take it at an extended level ($p = .973$). All of the above results are presented in Figure 2. The exact average score values and standard deviations for each subject are presented in Table S3.

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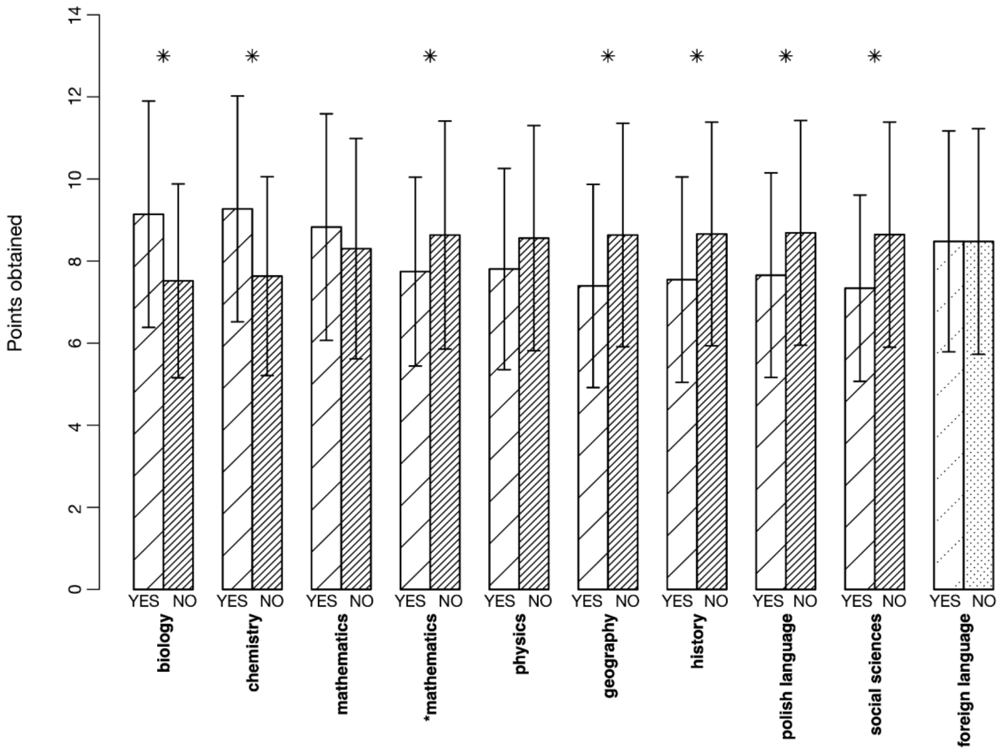
Figure 2

The Influence of Studying Different Subjects at an Extended Level on the Microbiological Awareness of Upper-Secondary School Students



Note. The height of the bars indicates the mean number of points obtained in the test. Error bars indicate standard deviation in designated groups. that study the subject at an extended level (YES) compared to those that do not (NO) Statistically significant differences between the groups is marked with solid line patterns ($p < .05$). Statistically insignificant differences between the groups are marked with dotted line patterns. $\varepsilon^2 > .01$ for the designated data groups is marked with asterisks. "*mathematics" indicates students who study mathematics at an extended level but not biology.

Significant differences were detected in the number of points obtained by people with a medical professional among their relatives compared to those who do not have such a person ($p = .003$). Students with a medical relative performed slightly better - $M = 8.7$ ($SD = 2.8$) versus $M = 8.3$ ($SD = 2.6$). However, no effect of relative health professionals on microbiological awareness was observed ($\varepsilon^2 = .0073$).

Statistical significance was not achieved in the case of differences in the number of points obtained depending on the place of residence ($p = .11$, $\varepsilon^2 = .0051$).

The number of points obtained differed significantly depending on the willingness to get vaccinated ($p = .012$). Students who were vaccinated or expressed the will to be obtained an average of 8.6 points ($SD = 2.8$). Those who were hesitant or strongly refused ever to be vaccinated against COVID-19 obtained an average of 8.0 points ($SD = 2.7$). However, no effect of willingness to get vaccinated on microbiological awareness was observed ($\varepsilon^2 = .0054$).

There were significant differences in the number of points obtained depending on the respondents' lifestyle ($p = .008$). After more detailed analysis, it turned out that the groups that showed significant differences were "physically and socially active" and "not active" ($p = .010$ - obtained from Dunn's test). On average, physically and socially active students obtained a higher score on the test ($M = 8.8$; $SD = 2.7$) than non-active students ($M = 8.1$; $SD = 2.7$). However, no effect of lifestyle on microbiological awareness was observed ($\varepsilon^2 = .0095$). For the remaining groups, no significant differences were found. All of the above results are presented in Figure 3.

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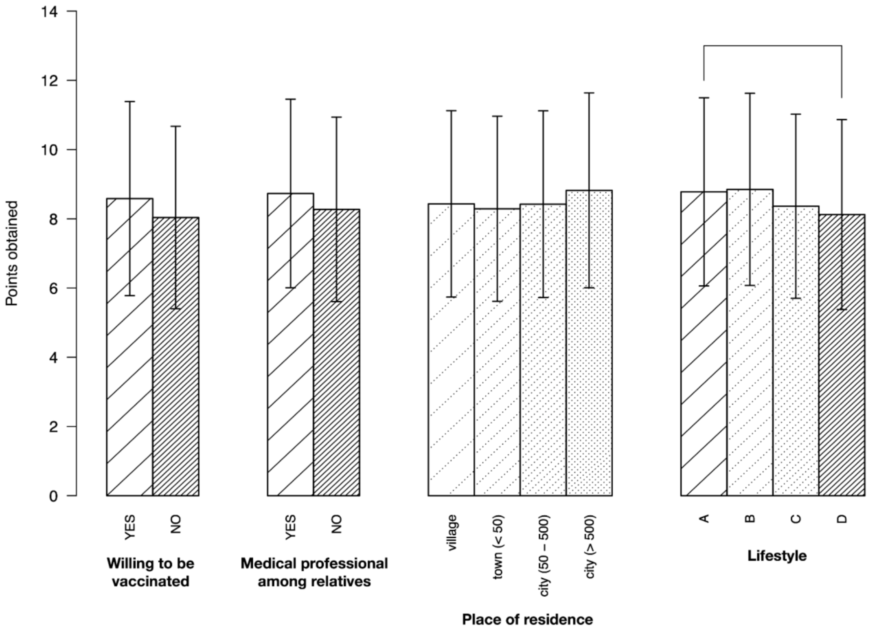
Figure 3
The Influence of Different Factors on the Microbiological Awareness of Upper-Secondary School Students



Note. The height of the bars indicates the average number of points obtained in the test. Error bars indicate standard deviation in designated groups. In the section "Willing to be vaccinated," students included in the group "YES" were vaccinated or planned to at the time of taking the questionnaire (low-density stripes). Students included in the group "NO" were hesitant or refused ever to be vaccinated against COVID-19 (high-density stripes). In the "Place of residence" section, the citizen number (thousands) of towns and cities where respondents lived is indicated. Rising citizen numbers of place of residence are indicated by increasing pattern density. In the section "Lifestyle," designated groups are "physically and socially active" (A), "physically active" (B), "socially active" (C), and "not active" (D). The decreasing activeness of designated groups is indicated by the rising density of the pattern. The statistical significance of differences between groups is marked with solid lines within the bars ($p < .05$). Dotted lines within the bars indicate no significant differences. In all groups of data, ε^2 was lower than .01.

Vaccination Willingness

Significantly more respondents from big cities (with a population of over 50 thousand residents) were willing to be vaccinated compared to respondents from smaller towns and villages (with a population of less than 50 thousand residents) ($p < .001$, $\varphi = .118$). Moreover, the difference in microbiological awareness in view of willingness to get vaccinated was slightly higher in cities (8.7 ($SD = 2.7$) vs. 8.0 ($SD = 2.6$)) than in small towns and villages (8.5 ($SD = 2.7$) vs. 8.1 ($SD = 2.7$)). However, these dissimilarities were statistically insignificant ($p = .128$ and $p = .06$, respectively).

No correlation was found between the willingness to get vaccinated and having a medical practitioner among relatives ($p = .060$), the lifestyle ($p = .214$), studying biology at the extended level ($p = .929$), nor any other subjects at the extended level.

Reasoning

The most frequently designated reasons for being against or hesitant towards the vaccination were the fear of side effects, insufficient research on the COVID-19 vaccine before its wide-range use, and the belief in the lack of vaccines' efficacy in preventing diseases in general (Figure 4). The will to vaccinate oneself was motivated mainly by the expected protection against the severe course of COVID-19 for the respondent, the will to end the pandemic, and the protection of relatives and loved ones (Figure 5).

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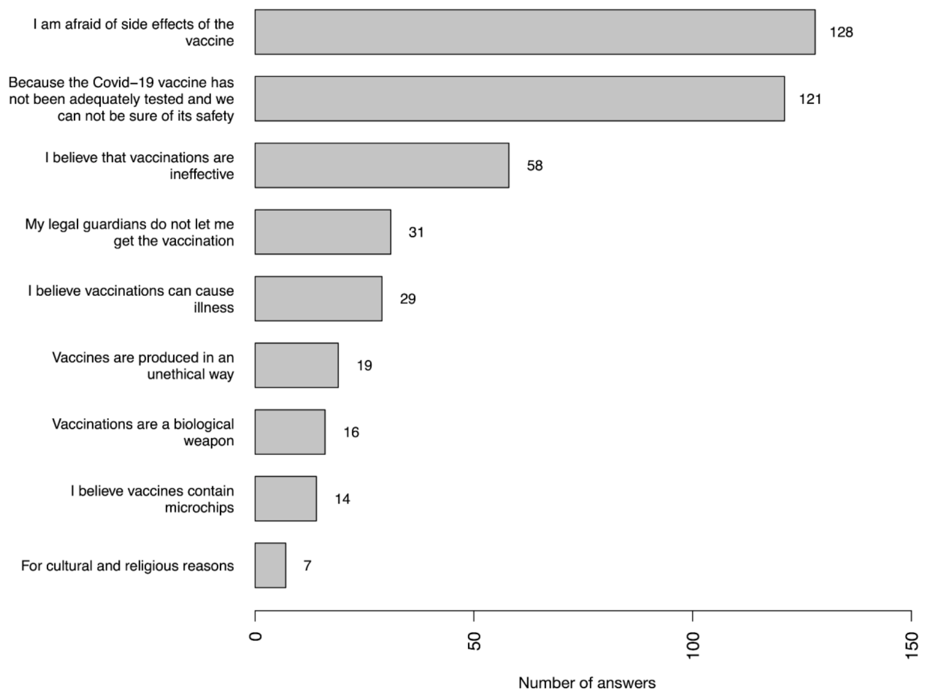
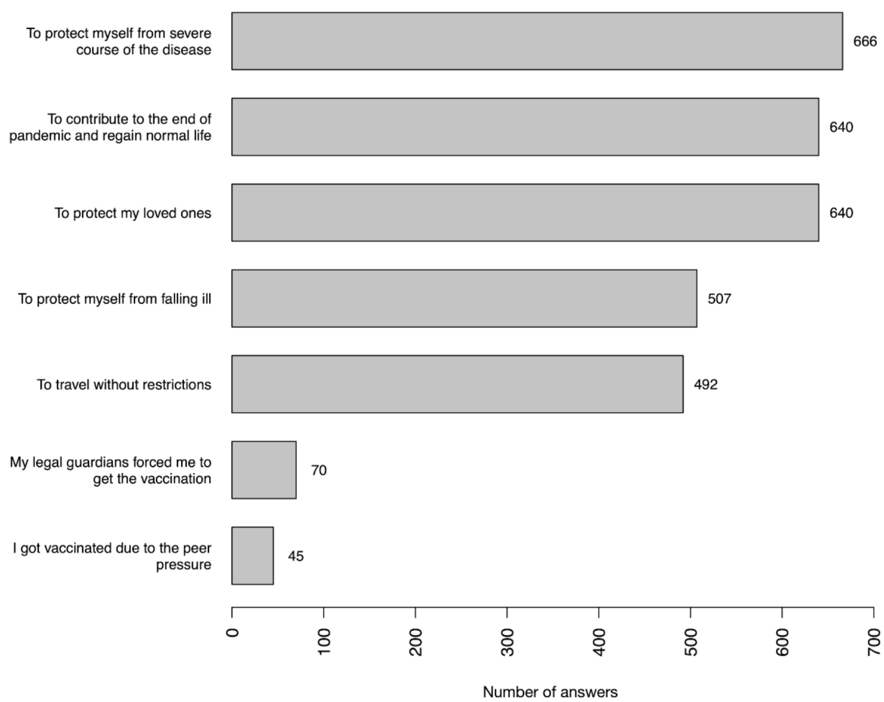
Figure 4
Reasons Why Respondents Do Not Want to Get Vaccinated against COVID-19



Note. The number of people who indicated each of the reasons is shown beside each bar.

Figure 5
Reasons Why Respondents Want or Have Already Got Vaccinated against COVID-19



Note. The number of people who indicated each of the reasons is shown beside each bar.

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Discussion

Among reasons against vaccination against SARS-CoV-2 that the respondents of the questionnaire indicated, the most common were:

- the vaccine has been available on the market for too short a time
- insufficient information about the vaccine;
- potential post-vaccination reactions and unwanted, long-term side effects (Figure 4, Figure 5).

In other studies, conducted so far (Al-Mistarehi et al., 2021; Scherer et al., 2021), the same reasons were indicated by 40-70% of respondents who were undecided or unwilling to get vaccinated.

The present results also confirmed the hypothesis that the school class profile influences microbiological awareness, where the most influential subjects were biology and chemistry (Figure 2). Surprisingly, even though it was possible to confirm that deepened knowledge of biology increases microbiological awareness, no clear proof was found that microbiological awareness increases the willingness to vaccinate. No relationship was observed between learning biology and the willingness to vaccinate either. This is, however, consistent with psychology studies implying that a higher level of education or intelligence may not always lead to challenging one's preexisting beliefs, but it may instead be used to support them (Driscoll, 2019; Hornsey, 2016; Lewandowsky & Oberauer, 2016; Sobkowicz & Sobkowicz, 2021).

Moreover, the obtained results may suggest that the presence of a medical practitioner among relatives influences microbiological awareness (Figure 3); however, the ε^2 was very low (see Results). To understand the anti-vaccination group's activity, Sobkowicz and Sobkowicz (2021) developed an Agent-Based Model that included four agent entities: doctors, patients, initiators, and messages in the infosphere. All agents were given an opinion about vaccination ranging from -2 (strongly against vaccines) to +2 (strongly supporting vaccines). The model assumed that patients might visit a doctor or get access to official information about vaccines and adjust their opinion according to the algorithm described in the publication. However, the doctors' opinion was prepared in a special way as it may have varied from +1 to +2 since some medical practitioners, for many reasons, may not want to get engaged in discussions about vaccines with their patients. As shown by the model, radicalizing anti-vaccination messages increases the number of unvaccinated patients. The trend may be reversed if the doctor's impact is greater than the messaging and if the number of anti-vaccination activists is low. Consequently, it may be that medical practitioners' influence has some potential to indirectly shift public opinion in favor of vaccinations by increasing microbiological awareness. However, the study conducted here does not provide clear evidence to support this conclusion.

In addition, it was impossible to confirm the phenomenon observed in the study conducted by Fazel et al. (2021). Researchers from Oxford have observed that people who are hesitant towards or against vaccinations are more likely to lead an unhealthy life (little exercise, smoking) and spend a lot of time on social media. It is imaginable that this relationship is absent among high school students in Poland. Nevertheless, data collected by Fazel et al. (2021) are more detailed and assess participants' lifestyles more accurately. Consequently, the lack of relationship was probably caused by the imperfection of the present study.

Lastly, the difference in the level of microbiological awareness between the vaccinated and unvaccinated living in cities was slightly bigger than the difference between the same groups living in smaller towns or villages in view of vaccination willingness. However, there was no direct difference in microbiological awareness between urban and rural students.

Therefore, it is plausible that in towns and villages, the social pressure not to vaccinate is more dominant than in cities, and when the pressure gets mitigated, microbiological awareness becomes more important. It is also worth mentioning that people living in rural areas are more likely to conform due to the lack of anonymity. Bourke et al. (2004) mentioned that although urban and rural citizens have approximately the same number of strong ties among their respective communities, rural residents usually have a significantly lower number of weak ties. This can result in a lack of anonymity among rural citizens compared to urban citizens.

It is also important to note that the introductory 1999 structural reform aimed to improve the quality of education in the rural areas of Poland (Wiśniewski & Zahorska, 2020). It succeeded in reducing the differences between urban and rural areas (Jakubowski, 2020), which is also proved by this study, considering that all questions were constructed based on Polish curriculum requirements (Table S2) and no differences in microbiological awareness between urban and rural areas were observed in high school students.

As a consequence of the 1999 reform, lower secondary schools prioritized hiring experts in fields such as

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physics, biology, and chemistry as teachers and financing equipment for laboratory classes (Wiśniewski & Zahorska, 2020). After the 2017 reform, numerous lower secondary schools were not closed down but became a formal part of local primary schools. Thus, younger children could continue classes in the same primary school they used to attend, and adolescents had lessons in a former lower secondary school building. Therefore, the lack of significant difference in microbiological awareness between rural and urban areas could result from the equipment and expert teachers that stayed in schools even after the 2017 reform. It may be speculated that the differences in health education that were present before the 1999 reform may result in the present social pressure not to vaccinate, which older inhabitants in rural areas could create. Consequently, high school students living in towns and villages are less willing to vaccinate, which was proved by the present study (see Results).

Given all of the obtained results, it may be presumed that microbiological awareness is not the most influential factor, and other components like filter bubble, social pressure, guardian consent, and cultural background may be more crucial in deciding whether or not to vaccinate. For example, it was suggested by Kahan et al. (2017) that it is a scientific curiosity rather than IQ or level of education that may lead to contradicting one's viewpoint. Considering the present results, it could be speculated that the level of biological knowledge can indirectly affect the willingness to vaccinate but is not the most important factor in the decision process.

It is important to note that by the time the study was conducted, barely half of children and adolescents in Poland (0-17 years old) and 57% of the general public had been vaccinated (Information Service of Republic of Poland, 2023; Statistics Poland, 2022), which is similar to the percentage of people declaring their willingness to be vaccinated. It can be concluded from this that most people with a favorable attitude toward vaccinations have already been vaccinated. Therefore, to increase vaccination coverage in the population, reaching those not in favor of vaccination is necessary. The present research shows that it is important to dispel all doubts about vaccinations and post-vaccination reactions among young people (Figure 4).

It could also be beneficial to rerun the study with a bigger group of students and a questionnaire that measures scientific curiosity, especially considering that there was no clear evidence for a difference in microbiological awareness between the vaccinated and the unvaccinated. Another option worth considering is rerunning the study to obtain more data on the social aspects of unwillingness to vaccinate and microbiological awareness in society as a whole rather than in high school students.

Last but not least, adding more questions should be considered to measure microbiological awareness more accurately before rerunning such a study. This would considerably diminish the issue with low ω hierarchical and ω total coefficients compared to ω asymptotic, which were obtained in the quality analysis of the knowledge test. In several cases, some researchers would also regard the corrected item-total correlations as unsatisfactory (Ladhari, 2010). Reevaluation of tasks is advised if a similar study is to be conducted.

Conclusions and Implications

The study confirms that the class profile influences microbiological awareness in a significant way, where the most influential subjects were biology and chemistry. Nevertheless, learning those subjects in an extended scope did not increase the willingness to vaccinate. It also remained unresolved whether microbiological awareness affects vaccination willingness. Data collected did not provide clear proof that factors such as lifestyle or a medical practitioner among relatives influence the level of microbiological awareness. The abovementioned factors did not change the desire to get vaccinated either.

It was determined that students' place of residence is an important factor in considering vaccination willingness. High school students living in small towns and villages in Poland were less willing to be vaccinated. It may be due to the higher social pressure of distrusting and opposing vaccinations, which might be more prevalent in rural areas than in big cities. Consequently, higher conformity of people living in rural areas could have a negative effect on vaccination willingness among high school students from towns and villages. Therefore, more effort should be put into health education and vaccination encouragement of society as a whole.

The reasons for vaccination unwillingness among Polish high school students were unraveled. It is advised that biology teachers use these results to address the uncertainties of students considering not only COVID-19 but also other illnesses. This could contribute to maximizing vaccinations in the Polish population.

It is suggested that a study with a bigger group and a methodology to measure scientific curiosity rather than microbiological knowledge might be necessary to determine the effect of education on vaccination willingness. Analyzing factors such as online infosphere would help resolve the relationship between the lifestyle or relative

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medical practitioner and the desire to get vaccinated. Larger scale research would also be useful to unravel whether the obtained, slight impact of lifestyle and relative medical practitioner on microbiological awareness is truly significant or just a result of the size of the study.

This preliminary but informative study shows how complex research on the willingness to vaccinate really is. Any future studies should focus on measuring a person's education or knowledge and factors like scientific curiosity, social pressure, and online community.

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Declaration of Interest

The authors declare no competing interest.

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Appendices

Supplementary Table 1 (Table S1) - Table containing questions asked in an online questionnaire with the specified aim for each question.

Supplementary Table 2 (Table S2) - Table containing learning objectives and curriculum requirements on which questions were based.

Supplementary Table 3 (Table S3) - Table containing the exact average score values and standard deviations of scores obtained in the test for students attending each subject studied on the extended level and those not attending it.

Table S1

Questions Asked in an Online Survey with the Specified Aim for Each Question

No.	Question from the survey	Aim of the question
Following questions aim to test students' knowledge and microbiological awareness.		
1.	In treatment of which diseases antibiotics are used? a. Bacterial diseases b. Viral diseases c. Fungal diseases d. I don't know	The question tests if participants possess knowledge about antibiotics usage in healthcare.
2.	"All bacteria are harmful" - do you agree with this statement? a. Yes b. No c. I don't know	The question tests if participants possess knowledge about symbiotic bacteria.
3.	Finish the sentence (you can choose more than one answer): "Antibiotics are effective in the treatment of…" a. Flu b. Quinsy c. Mononucleosis d. Common cold e. Lyme disease f. Gonorrhoea g. Tetanus h. Mumps i. Chickenpox j. COVID-19 k. I don't know	The question tests if participants possess knowledge about antibiotics usage in disease treatment and pathogenesis of highlighted diseases.
4.	Which microorganisms listed below can cause pneumonia? a. Bacteria b. Viruses c. Fungi d. I don't know	The question tests if participants know which microorganisms can cause pneumonia.
5.	Which of the agents listed below are efficient in daily hand sanitation? You can choose more than one answer. a. Alcohol 20%-40% (e.g., vodka, ardent spirits) b. Alcohol 60%-70% c. Pure alcohol 96% (spirits) d. Water with soap e. Cold water f. Ready-to-use sanitizers from pharmacy	The question tests participants' knowledge about sanitizing agents.

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No.	Question from the survey	Aim of the question
6.	Franek returned home from school. In the kitchen he found a piece of cake, partially covered in green residue. He cut off the green part and ate the rest of the cake. In your opinion, was it safe for his health? a. Yes b. No c. Different answer (submitted by participant)	The question tests participants' basic knowledge about fungi, fungal toxins and healthy eating.
7.	Does the "five seconds rule" work? a. Yes b. No c. I don't know this rule	The question tests participants' elementary knowledge about hygiene basics, healthy eating and health-promoting practices. "Five seconds rule" concerns food that fell on the floor and the common assumption that it is safe to eat if it was picked up before five seconds passed.
8.	What are cyanobacteria? a. Small plants b. Water fungi c. Bacteria d. Protists e. I don't know	The question tests participants' knowledge about cyanobacteria. NOTE: although the English name "cyanobacteria" explains what kind of organisms they are, in Polish there is no such connotation (Polish word for cyanobacteria is "sinice").
9.	Why is swimming in cyanobacteria-blooming water dangerous? a. Cyanobacteria are pathogenic and can cause e.g., infections of urinary tract b. Cyanobacteria produce dangerous toxins c. Contact with cyanobacteria can cause skin burns and rashes d. This activity is not dangerous e. I don't know	The question tests participants' knowledge about cyanobacteria, bacterial toxins and algal blooms.
The following questions aim to find participants' reasons and motivations to vaccinate against COVID-19 and reasons for not wanting to do so.		
10.	Are you vaccinated against COVID-19? a. Yes b. No, but I want to c. No and I still don't know if I want to d. No, I don't want to	The question aims to determine participants' willingness to vaccinate against COVID-19.
11.	If you answered you do not want to vaccinate against COVID-19 in the previous question, answer why. a. I'm afraid of side effects of vaccination b. I consider vaccinations ineffective c. Because of cultural or religious reasons d. Vaccines are produced unethically e. I think vaccines contain microchips or other devices f. I think vaccines can cause diseases g. Vaccine against COVID-19 wasn't subjected to enough number of trials and tests h. We cannot be sure if it's safe i. Vaccinations are a form of biological weapon j. My parents/caregivers did not allow me to vaccinate k. Other answer	The question aims to determine reasons why participants are not vaccinated.

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No.	Question from the survey	Aim of the question
12.	If you answered you are vaccinated or you are, willing to vaccinate against COVID-19, why a. I want to be protected against COVID-19 b. I want to be protected from severe consequences of COVID-19 c. I want to protect my relatives d. I want to protect people who cannot be vaccinated against COVID-19 or suffer from immunodeficiency e. I want to contribute towards ending of pandemic f. Because of social pressure g. My parents/caregivers told me to vaccinate h. I want to travel without restrictions i. Other answer	The question aims to determine reasons why participants are vaccinated.

Table S2

Learning Objectives and Curriculum Requirements on Which Questions in the Online Questionnaire Were Based

Subject	Learning objectives	Curriculum requirements
Natural science	I. Knowledge. 4. Acquiring knowledge about systems of the human body (skeletal, respiratory, digestive, blood circulation, reproductive, nervous). II. Skills and practical usage of knowledge. 5. Application of rules concerning self-healthcare, including disease prevention.	IV. Me and my body. Student: 1. Lists systems of the human body: skeletal, respiratory, digestive, blood circulation, reproductive, nervous and explains their basic functions; 6. Explains basic rules of self-body care and care about the surrounding environment. V. Me and my surroundings. Student: 2. Explains ways pathogens infect the human body, explains ways of disease prevention.
Biology in primary school	V. Knowledge of factors of human health. Student: 1. Analyzes the connection between their actions and maintaining health and recognizes situations demanding consultation with physicians.	II. Diversity of life. 2. Viruses - non-cellular forms of matter. Student: 2) explains ways of spreading and prevention of viral diseases (flu, chickenpox, rubella, mumps, measles, AIDS) 3. Bacteria - unicellular organisms. Student: 1) lists bacterial habitats; 4) explains ways of spreading and prevention of bacterial diseases (tuberculosis, Lyme disease, tetanus, salmonellosis); 5) explains importance of bacteria in natural environment and human body 4. Protists - organisms of diverse cellular structure. Student: 4) explains ways of spreading and prevention of diseases caused by protists (toxoplasmosis, malaria). 6. Fungi - heterotrophic organisms. Student: 5) explains the role of fungi in the natural environment and human life. III. Human body 6. Immune system. Student: 3) compares the mechanism of action of vaccines and antivenom; lists medical indications of their use and justifies the necessity of mandatory vaccinations. 12. Reproduction and development. Student: 6) explains ways of prevention of sexually transmitted diseases.

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Biology in upper secondary school	Extended programmes: V. Deepening the knowledge of human health factors. Student: 1. plans health-promoting activities; 2. understands the importance of preventive screening and recognizes situations demanding consultation with physicians; 5. acknowledges the importance of research in disease prevention. Primary programmes: II. Deepening the knowledge of human health factors. Student: 1. plans health-promoting activities; 2. understands the importance of preventive screening and recognizes situations demanding consultation with physicians; 4. acknowledges the importance of research in disease prevention.	Curriculum for high school, extended programmes: VI. Bacteria and archaeans. Student: 5. explains the importance of bacteria in the natural environment and human body, including pathogenic bacteria and bacterial diseases (tuberculosis, tetanus, Lyme disease, salmonellosis, syphilis, gonorrhea). VII. Fungi. Student: 5. explains ways of infection and prevention of diseases caused by fungi (skin mycosis, reproductive organs mycosis, lung mycosis) VIII. Protists. Student: 5. explains ways of spreading and prevention of diseases caused by protists (malaria, toxoplasmosis, lambliosis, amoebiasis, trichomoniasis) XII. Viruses, virions, prions. Student: 6. explains ways of infection and prevention of viral diseases (rabies, AIDS, poliomyelitis, HPV-related diseases, flu, measles, chickenpox, rubella, mumps, viral hepatitis, some types of cancer).

Table S3

Exact Mean Score Values (M) and Standard Deviations (SD) of Scores Obtained in the Test for Students Attending Each Subject Studied on Extended Level and Those Not Attending It

Subject	Participants studying the subject on extended level		Participants not studying the subject on extended level	
	M	***SD***	***M***	***SD***
Biology	9.1	2.8	7.5	2.4
Chemistry	9.3	2.7	7.6	2.4
Mathematics (extended biology included)	8.8	2.8	8.3	2.7
Physics	7.8	2.5	8.6	2.7
Geography	7.4	2.5	8.6	2.7
History	7.5	2.5	8.7	2.7
Polish	7.7	2.5	8.7	2.7
Social studies	7.3	2.3	8.6	2.7
Foreign language	8.5	2.7	8.5	2.7
Mathematics (extended biology excluded)	7.7	2.3	8.6	2.8

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INTEGRATION OF SOCIOSCIENTIFIC APPROACH AND DESIGN THINKING: AN ENTREPRENEURIAL CREATIVE THINKING MODULE FOR STEM EDUCATION

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Nyet Moi Siew

Abstract. *This study was conducted to i) ascertain the validity, reliability, and feasibility of a module based on the socioscientific issue approach and design thinking model (SIA-DT), and ii) assess its effects on the entrepreneurial creative thinking (ECT) in STEM education. The first phase of ECT module validation was conducted with the assistance of three expert evaluators and 32 students. A 5-point Likert scale questionnaire and the ECT test were used to collect data. The second phase consists of evaluation using a quasi-experimental design with a Pre-Post Test of Non-Equivalent Control Groups. A total of 64 Form Four students were divided into two groups: SIA-DT (n = 32) and control (n = 32). The ECT module has a high validity value and an acceptable Cronbach's alpha reliability of .92. The ECT Module's feasibility was substantiated by a mean score of 4.71. The results of the independent-sample t-test prove that there is a significant difference in the post-test for students in the SIA-DT group compared to the control group in ECT and five constructs of ECT. In conclusion, these findings demonstrate that the ECT Module is valid, reliable, and feasible in STEM education and that it is effective in enhancing students' ECT.*

Keywords: *design thinking model, entrepreneurial creative thinking, module development, socioscientific issue approach, STEM education*

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Introduction

The application of entrepreneurial thinking in teaching and learning can produce potential entrepreneurs capable of innovating new ideas or products by leveraging existing opportunities. According to Bacigalupo et al., (2016), implementing entrepreneurial thinking in students through training and experiences in school will result in students who can think like entrepreneurs identifying opportunities in the market and exploring suitable ways to capitalize on them. A student with an entrepreneurial mindset will always be innovative in solving problems (Nadelson et al., 2018).

Therefore, a learning model that nurtures entrepreneurial thinking in teaching and learning at schools needs to be introduced. Based on this need, Buang et al. (2009) aimed to understand the entrepreneurial scientist's thinking that led to innovative science-based products. Their qualitative findings indicated that respondents integrated entrepreneurial thinking and scientific process skills in producing innovative science-based products. As a result, they proposed the Science Entrepreneurial Thinking (SET) learning model that can be used as a teaching model in the science curriculum at the primary and secondary school levels. Based on integrating science and entrepreneurship disciplines, the SET learning model consists of five steps: observation, new ideas, innovation, creativity, and value. However, the SET learning outcomes conclude with students gathering community perspectives on product ideas through surveys. Subsequently, the analysis of these surveys is presented to their peers in the classroom. The students are not guided through the steps to introduce their product ideas to the market.

New ideas or products may not necessarily guarantee their ability to penetrate the market, especially in a rapidly changing technological and market environment. These products might be introduced too early or too different to be accepted in the market (Perry-Smith & Coff, 2011). Fresh ideas or products might hold value, yet their true worth is determined by their reception in the market (Della Corte & Del Gaudio, 2017). Therefore, in the endeavour to innovate ideas or products, creativity can elevate an idea or product to have value in the market (Shepherd & Patzelt, 2011). Creativity in the entrepreneurial context not only emphasizes extraordinary or unique

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products, but it should also have the capability to penetrate the market and generate profits (Perry-Smith & Coff, 2011).

It is clear here that the element of creativity in entrepreneurship can be highlighted as the creative thinking of entrepreneurs in creating products and marketing them creatively to generate profits. Therefore, the application of entrepreneurial creative thinking should equip students with fundamental skills and knowledge to innovate and market ideas or products, subsequently generating income in a dynamic technological and market environment.

Kennedy and Odell (2014) noted that STEM education applies the process of designing solutions to complex contextual problems using current tools and technologies (p. 246). Entrepreneurial creative thinking opens up space for students to think more broadly to explore new ideas in STEM-based problems. Owens et al. (2017) stated that the socioscientific issue approach helps students to develop and evaluate arguments related to current issues and connect them to the interests of society. Therefore, there is a need in fostering entrepreneurial creative thinking in STEM education to increase students' awareness of current issues in the society and encourage them to think outside the box in finding solutions to problems through the design process.

According to Jacobson et al. (2006), a teaching and learning module as a training package helps students understand or master skills or learning units effectively. Hence this research was carried out to determine whether the ECT teaching and learning module developed as a result of the integration of socio-scientific approach and design thinking in STEM education can develop ECT of students. The necessity of this study also aligns with the requirements of the Malaysian Education Development Plan 2013-2025, which encourages the incorporation of Entrepreneurship Cross-Curricular Elements into teaching and learning (Ministry of Education Malaysia, 2012).

Theoretical Framework

The design and development of the ECT teaching and learning module based on the socio-scientific approach and design thinking model are executed through the analysis of various elements, such as the socio-scientific approach, design thinking model, implementation of STEM education in schools, understanding of students' learning styles in secondary school, and their correlation with theories and learning models. As the produced module is focused on Form Four students in secondary school, it applies both Piaget's Cognitive Constructivism Theory (Piaget, 1976) and Social Constructivism Theory (Vygotsky, 1978).

In line with the research subject, which involves Form Four students, the constructivism theory is appropriate for creating an active learning environment. This theory emphasizes engaging in activities that promote active knowledge construction (Dogru & Kalender, 2007), enhancing higher-order thinking (Bogar et al., 2012), and training students to think critically, analytically, and forward-thinking (Boghossian, 2012). Form four students are categorized at the fourth stage, the formal operational stage, in their cognitive development as proposed by Piaget's Cognitive Constructivism Theory. At this stage, Piaget assumed that children's patterns of reasoning are complete, allowing them to use logic, comprehend concrete and abstract concepts, engage in reasoning, and solve problems through assumptions.

This module also emphasizes cooperative learning through group-based product-creation activities. In line with Social Constructivism Theory, Vygotsky also highlights the significance of cooperative learning, which is crucial in decision-making processes. This includes assigning tasks in pairs or small groups to maintain student motivation. This aligns with the implementation of this study, which divides the research subjects into small groups of 5 to 6 individuals. Vygotsky believed that for effective learning, students need to engage in self-talk in a motivating and guiding manner, gradually internalizing the spoken guidance. This way, students can develop and become more competent in specific areas. This internalized interaction forms the basis for teaching thinking skills (McLeod Saul, 2007).

Furthermore, Vygotsky's Social Constructivism Theory suggests the active involvement of students, aiding them in exploratory learning, providing guidance through explanations, demonstrations, and verbal instructions, as well as delivering information and cooperative learning. This theory emphasizes guided exploration by the teacher, where the teacher employs questioning methods to prompt students to seek answers to questions (Kubli, 2005). This principle also aligns with the implementation of this study, where the socio-scientific approach exposes students to social issues and encourages them to find scientific solutions. The posed questions act as guided explorations for the students. Although students engage in the exploration process, they still receive assistance from knowledgeable teachers and peers.

The researcher also acknowledges the significance of pedagogical principles in the teaching and learning

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process in secondary schools, supporting the cognitive and social construction of information and knowledge. This study employs the Socioscientific Issue Approach (SIA) Model (Sadler et al., 2017) and the Design Thinking (DT) Model (Adapted from Hasso Plattner Institute of Design at Stanford University, 2019).

According to Sadler et al. (2017), the SIA learning model encompasses three phases. In implementing the first phase, students discover or are introduced to a specific issue. Students are guided to engage in discussions about the stated issue, building their understanding by connecting it with scientific ideas and societal awareness. In the second phase, a process of scientific practice takes place, where students reason about the social and scientific components related to the issue from the first phase. In this case, students actively seek connections between the social issue, scientific knowledge, and scientific practices, making the issue more relevant for resolution (Sadler et al., 2017). Students strive to solve the issue based on societal values during the final phase. They are encouraged to synthesize ideas and practices and actively express ethical ideas and opinions.

The Socioscientific Issue Approach model is integrated with the Design Thinking (DT) model in creating this module. Plattner (2019) from the Institute of Design at Stanford University presented five stages of the DT learning model as a framework for solving real-world problems. These stages are empathize, define, ideate, prototype, and test. In the empathize stage, students seek to understand user needs to enable them to set aside their assumptions and gain direct insights into user needs (Chaudhari, 2021). Students gather user problems obtained during the empathize stage in the define stage. They then analyse, observe, and synthesize these problems to determine the core issues that require solutions. Students also formulate problem statements during this stage. Moving on to the third stage of the DT model, ideation, students focus on generating creative ideas and organizing solution ideas for the problem statements. Various ideation techniques such as Brainstorm, Brainwrite, and SCAMPER are employed. Brainstorming the Worst and Possible Ideas is usually used to stimulate free thinking, helping students develop the best solutions for users (Chaudhari, 2021). Subsequently, in the prototype stage, students are required to construct prototypes. At this point, students transform their solution ideas into tangible products. In the final stage, testing, students test and receive user feedback on the prototypes they have built. Feedback from the public, users, experts, and stakeholders enables students to decide if the prototype aligns with the defined problem-solving objectives or if an iterative process is necessary.

The researcher employs a comprehensive integration method (Swartz & Parks, 1994) to combine the socioscientific issue approach with the design thinking model (SIA-DT). In this method, entrepreneurial creative thinking is identified beforehand and taught simultaneously with the subject content. Comprehensive integration is taught using five teaching steps: (i) introduction, (ii) active thinking, (iii) thinking about thinking, (iv) reinforcement exercises, and (v) application of thinking. In this context, both components (subject content and entrepreneurial creative thinking) are interrelated and implemented in each process.

For the design and development of the Entrepreneurial Creative Thinking teaching and learning module, the researcher adopted the ADDIE Model (Branch, 2010), which consists of five phases: analysis, design, development, implementation, and evaluation. The ADDIE Model was chosen because it centres on student-centred learning activities and goal-oriented instructional design and enables students to engage in meaningful actions and solve problems practically. The theoretical framework for the design and development of the Entrepreneurial Creative Thinking teaching and learning module is illustrated in Figure 1.

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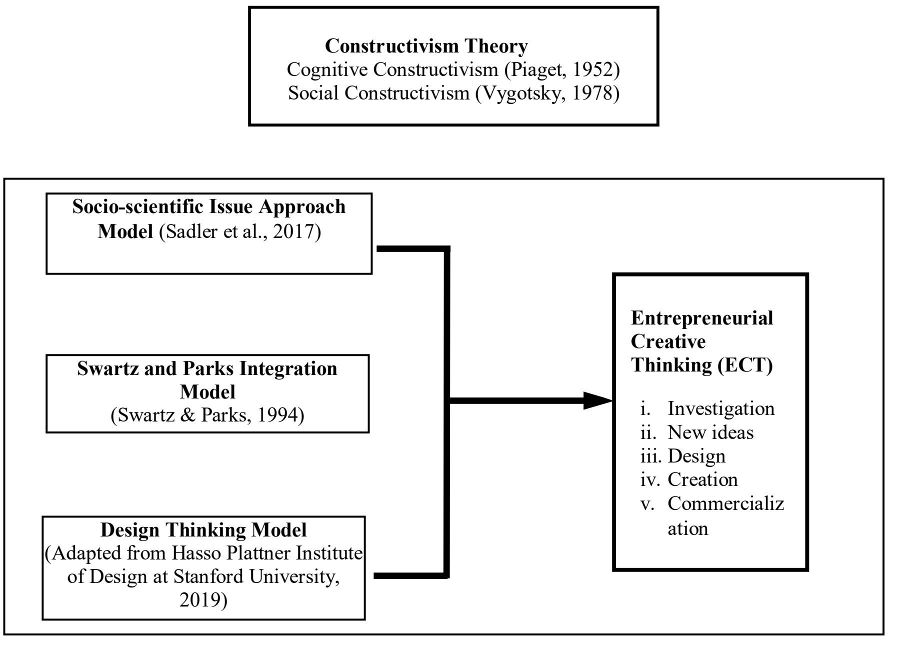
Figure 1
Theoretical Framework in the Design and Development of the Entrepreneurial Creative Thinking Teaching and Learning Module



Research Aim and Questions

This study was conducted to design and develop a teaching and learning module that integrates the socio-scientific issue approach and design thinking (SIA-DT) to enhance Entrepreneurial Creative Thinking (ECT) in STEM Education for Form Four students. There are three research questions that guide this study:

i. Is the developed ECT module valid, reliable, and feasible for Form Four students?
ii. Are there significant differences between pretest and posttest scores for the SIA-DT experimental group regarding entrepreneurial creative thinking and all constructs of entrepreneurial creative thinking?
iii. Are there significant differences in entrepreneurial creative thinking and all constructs of entrepreneurial creative thinking between Form Four students in the SIA-DT experimental group and the control group?

Research Methodology

Design

This study employs a descriptive and quasi-experimental research design. The descriptive study assesses the validity, reliability, and feasibility of the Entrepreneurial Creative Thinking (ECT) teaching and learning module. On the other hand, a quasi-experimental design is applied to determine the effects of the ECT module on the entrepreneurial creative thinking of Form Four students. The study was conducted for 12 weeks, from November 2022 to January 2023.

Sample

The descriptive study involves 32 Form Four students and three expert assessors. When assessing the reliability of a newly developed instrument, a sample size of 30 respondents is considered adequate (Chua, 2011). In the quasi-experimental study, a total of 64 Form Four students were involved. They were randomly selected from two rural secondary schools in Tawau, Sabah, Malaysia. These students were divided into the SIA-DT experimental group (*n*=32) and the control group (*n*=32). Among them, 28 (44%) were male, and 36 (56%) were female. About

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23% of the student's parents worked in the government sector, while the remaining 77% worked in the private and self-employed sectors.

Ethical Considerations

At the initial stage of the study, the researcher obtained consent from the principals, teachers, and students involved as research subjects. All research subjects were provided with informed consent letters to seek permission from their parents to participate in the research. The consent letter detailed the students' involvement in the research and the parental agreement, indicating their understanding of the research purpose. All respondents were informed about their responses' confidentiality and were assured that they could withdraw from the study without any penalty.

Descriptive Analysis

Analysis Phase

The main objective of developing this Entrepreneurial Creative Thinking (ECT) module is to nurture and enhance the entrepreneurial creative thinking of Form Four students in STEM Education taught within the Science subject. To achieve this instructional objective, the researchers conducted an analysis of student needs and the context. During the needs analysis phase, the researchers conducted semi-structured interviews with three Form Four science teachers in Tawau, Sabah, on November 15, 2022. These interviews aimed to understand how to enhance ECT within STEM education. Through these interviews, the Form Four science teachers indicated they had limited knowledge about implementing STEM in the Science subject. They stated that despite the media coverage of STEM, they had not received formal exposure to STEM implementation in their subject. They also acknowledged not understanding entrepreneurship concepts clearly and were only familiar with entrepreneurship through cross-curricular elements within the classroom. They also expressed their lack of understanding regarding the socio-scientific issue approach and design thinking. One of the interviewed teachers had heard of the socio-scientific issue approach but had not yet implemented it. All the teachers shared feedback that they lacked exposure to ECT concepts and its teaching process due to the absence of guidance or learning modules related to ECT implementation in secondary schools. The interviews also revealed that the teachers had not received any training or courses related to ECT.

In analysing the students and context, the criteria used were adapted from Carlton, Kicklighter, Jonnalagadda, and Shoffner's idea (2000), which focused on students' prior knowledge about Unit 1.1, "Personal Protective Equipment," and Unit 10.4, "Health Products," within two themes of the KSSM Form 4 Science Curriculum: "Safety and Health" and "Chemistry in Medicine and Health." A questionnaire was utilized to gather information about students' proficiency levels in drawing skills, product creation skills, and using digital technology for commercial purposes. A total of 30 students were selected to provide feedback for this analysis. The analysis results indicated that all the assessed criteria were at a moderate level.

Therefore, the findings from this interview have provided strong justification to the researcher for designing the ECT Module as a guide for secondary school teachers to enhance Entrepreneurial Creative Thinking (ECT) in STEM Education among secondary school students.

Design and Development Phase of ECT Module

The ECT Module is designed by adapting the socio-scientific issue approach, which involves introducing social issues to students, helping them analyse the social and scientific components of the issues, and encouraging them to find solutions based on societal values. To assist students in creating products to address the socio-scientific issues presented, the design thinking model is utilized as a guide. These models are integrated through the Swartz and Parks (1994) framework for integrating thinking.

This module has six activities, including daily lesson plans, issues, stimuli, implementation procedures, and activity scoring rubrics to assist teachers in the implementation process. These activities are built according to the latest Standard Curriculum and Assessment Document for Form 4 Science under the KSSM by the Ministry of Education Malaysia (MOE). A total of six learning units have been designed under the themes of Safety and Health

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and Chemistry in Medicine and Health for the Form 4 Science KSSM subject. These units include Fabric Face Cover, Face Shield, Face Mask, Paper Soap, Pocket Hand Sanitizer, and Wet Disinfectant Tissue. Each activity is allocated 135 minutes. However, the suggested time for conducting these activities can be adjusted according to the school's teaching and learning (TL) schedule, as the steps involving product creation and commercialization are often carried out outside of regular TL hours.

This module is developed to cultivate Entrepreneurial Creative Thinking (ECT) in the Science TL at secondary schools through five steps: (i) investigation (conducting an investigation focusing on socio-scientific issues while considering user needs), (ii) generating new ideas (seeking new ideas through socio-scientific reasoning that fulfils user needs), (iii) design (formulating new products through sketching), (iv) creation (constructing products based on societal values), and (v) commercialization (introducing products to the community through digital technology). These five steps are adapted from the SET model by Buang et al. (2009), extracted based on the integration of steps from the DT model and the socio-scientific approach, as illustrated in Table 1.

Table 1
Teaching Entrepreneurial Creative Thinking Through the Integration of Socio-scientific Issues and Design Thinking Process Model

Socio-scientific Issues Approach Model (SIA) (Sadler et al., 2017)	Process of Design Thinking (DT) Model (Hasso Plattner Institute of Design at Stanford University, 2019)	Integration of Socio-scientific Issues Approach (SIA) and Design Thinking (DT) Models
Phase 1 Identifying Issue Focus Building Understanding of Socio-Scientific Issue	**Building Empathy** Investigating and Understanding User Needs	**Investigation** Conducting an investigation focused on socio-scientific issues while considering user needs
	Determining Scope Synthesizing findings while considering user problems and needs	
Phase 2 Engagement Involving students in acquiring scientific knowledge, scientific practices, and socio-scientific reasoning practices	**Idea Generation** Creative generation and organization of ideas	**New Idea** Searching for new ideas through socioscientific reasoning that meets user needs
		Design Formulating new ideas through sketching
Phase 3 Synthesizing Ideas and Practices Resolving issues based on societal values	**Prototyping** Building a prototype	**Create** Building a product based on societal values
	Testing Testing the prototype to gather feedback from users	**Commercialization** Introducing the product to the public through digital technology

In planning the activities, the researcher identifies socio-scientific issues that trigger ideas at each step of the ECT, ultimately leading to product creation. A socio-scientific issue that resonates with students at this time is the outbreak of COVID-19. Issues related to the transmission of COVID-19 are highly relevant to be linked with unit 1.1 on safety equipment and unit 10.4 on health products under the Safety and Health theme and the Chemistry in Medicine and Health theme. Through the steps of ECT, students will attempt to solve the problems users face by creating personal protective equipment and health products that can help contain the spread of COVID-19 while meeting user needs. Some examples of socio-scientific issues provided are as follows:

> Nowadays, users are advised to use a germ-killing liquid containing alcohol levels between 60 to 80 per cent to eliminate germs on their hands' surfaces. Similarly, the same percentage is recommended for alcohol-free germ-killing liquids that use a chemical compound called quaternary ammonium, specifically benzalkonium chloride. Alcohol concentrations exceeding 80 per cent are less suitable due to their quick-drying nature, which can cause the skin to become dry and cracked. Among the types of alcohol-based chemical compounds used in germ-killing liquids are ethanol (ethyl alcohol), "rubbing alcohol," or "isopropyl alcohol." The application of the liquid is similar to handwashing, but the process is quicker because germ-killing liquids dry rapidly. For maximum effect, it is highly recommended to thoroughly wash hands to ensure there is no dirt hindering the germ-killing liquid when applied to the skin's surface. The question of how we can create a portable hand sanitiser convenient for users arises.

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Based on the given socio-scientific issue, students are required to create a product that addresses the problem using the guidance of the five steps of ECT. In the first stage, students investigate the socio-scientific issue by formulating questions to understand the issue, its relationship with science, and its relevance to society. Through engagement and discussions with the real-life community concerning the issue, students can set aside their assumptions and comprehend the community's needs or the problems that must be resolved.

In the second stage, students are provided with a foundation to actively engage in imaginative thinking and explore new ideas to solve the problem and meet user needs. Through socio-scientific reasoning practices, while considering user problems, students strive to present unique and original ideas.

In the third stage, students are encouraged to synthesize their ideas and design new products through sketching. Considering societal values, students creatively arrange their ideas and select a few that they believe are most suitable for solving user problems. These chosen ideas are then translated into sketches. In the fourth stage, students translate these sketches into actual product designs. The products they create are constructed using local raw materials deemed appropriate for the production of the products.

In the fifth stage, students test the product by obtaining user feedback and considering ways to commercialize the product. This stage involves branding the product, pricing strategies, determining distribution channels, and creating marketing campaigns through suitable digital market channels in line with the Fourth Industrial Revolution. At this stage, students apply basic digital marketing skills through product, price, place, and promotion strategies, aligning them with digital technology advancements to generate revenue.

Assessment Phase

The assessment phase is carried out to interpret evidence and the quality of the teaching product before and after its implementation (Branch, 2009). As suggested by Branch (2009), the assessment is conducted in two phases: before and after the implementation of the ECT Module. Cohen and Swedlik (2018) emphasise that a suitable module exhibits high validity and reliability.

In the first assessment phase, the researcher conducts expert validation of the content of the ECT Module. Rubio et al. (2003) recommended involving at least three experts in the field under study to ensure that the domains contained in the assessment instrument truly represent the studied area. The module assessment form is provided to the experts to enable them to provide clear feedback on pedagogical content (socio-scientific approach, design thinking, and STEM education), an overview of activities, the appropriateness of each lesson plan, learning standards, the overall sequence of activity units, the integration of the five steps of entrepreneurial creative thinking, and written comments to enhance the module.

The second assessment phase is conducted to assess the reliability and feasibility of the module. To ensure the reliability of the ECT Module, a questionnaire set adapted from Ahmad (2022) is provided to the 32 study subjects in the SIA-DT group after the intervention using the module is carried out. Aung et al. (2021) have indicated that questionnaires based on activities exhibit higher reliability indices compared to module objectives. The ECT Module comprises six activities, and each activity is assessed by five items using a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The items address whether each activity conducted can help respondents cultivate the five constructs of entrepreneurial creative thinking following the module's learning outcomes. All 30 items are presented in a language that is appropriate and clearly understood.

To ensure the ECT Module's implementation in the TL for Form Four students, the researcher distributed a questionnaire to 20 Form Four science teachers. The teachers were requested to assess the feasibility level of the module by indicating their level of agreement on a scale from one to five for various aspects of the module, including the activities within the module, the integration of SIA and DT, and an overall assessment of the module.

Quasi-Experimental Study

The experimental research phase involves the implementation of the ECT teaching and learning module and assessing its effectiveness during classroom teaching and learning sessions. In line with this, the quasi-experimental Non-Equivalent Control Group Pre-Post Test design is used. A total of 64 Form Four students were randomly selected from two rural secondary schools in the Tawau district and divided into the experimental group (SIA-DT, n=32) and the control group (n=32). The research subjects in the experimental group received the ECT module, which covers

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six learning units over 12 weeks from November 2022 to January 2023. Each learning unit in this module consists of three sessions that take 180 minutes. A total of 6 teaching periods per week (180 minutes) were allocated for Form Four science lessons, each lasting 30 minutes. The researcher suggests that teachers complete one set of learning units in the ECT Module for two weeks. One week is dedicated to implementing the steps in the module, while the second week involves creating and producing marketing advertisements through digital technology. Teachers can also conduct module activities outside the formal teaching periods, depending on availability. On the other hand, students in the control group are exposed to the conventional design model production method without incorporating the socio-scientific issue approach and design thinking model.

To assess the module's effectiveness, the Entrepreneurial Creative Thinking Test (ECTT) instrument developed by the researcher was utilized. This instrument has been validated, proven reliable, and deemed suitable for evaluating the entrepreneurial creative thinking of Form Four students. The ECTT consists of 10 items that require students to respond to statements, generate idea sketches, and propose product marketing strategies using technological elements. The items were developed based on the five constructs of Entrepreneurial Creative Thinking. The ECTT prompts students to address the issue of using face shields and masks separately and in combination. The context of producing a combination of face shields and masks was chosen as it is included in the Curriculum and Assessment Document under the Safety and Health theme. Students were provided with ten-item questions organized according to the five ECT constructs—investigation, new idea generation, design, creation, and commercialization—to enable them to structure their responses and consequently lead to the desired outcomes. Scoring for the ECTT was conducted based on the scoring scheme by Ho et al. (2013). Each item presented in this test carried a minimum score of 0 and a maximum score of three. Meanwhile, the scores for each construct ranged from 0 to 6. All items accumulated a total score of 30.

Data Analysis

Descriptive study data was obtained by calculating percentages, means, and standard deviations. On the other hand, inferential study data was obtained through analysis using IBM SPSS (version 26). For this analysis, the significance level was set at .05.

Research Results

Content Validity

The researcher utilized the services of three expert individuals in entrepreneurial thinking, design thinking, and STEM education. In determining the experts' agreement on content validity, the researcher also employed the Content Validity Index (CVI) based on each item on the scale (I-CVI) as well as the overall scale (S-CVI/Ave), following the approach outlined by Polit et al. (2017). The obtained Content Validity Index Item (I-CVI) values for the standard assessment and learning outcomes aspects were below .78. This suggests that the standard assessment and learning outcomes aspects need refinement based on expert group comments and suggestions. The Content Validity Index Scale (S-CVI/Ave) value of .93 for the entire module meets the criteria set for new instruments, indicating that the content validity of the ECT Module, according to the expert panel, is high and acceptable (Polit et al., 2017).

In line with the experts' recommendations, several improvements have been made to the content and activities of the ECT Module; 1) The activities should incorporate an introduction to current issues to help students understand the relevance of the topics under discussion, 2) The term 'marketing' needs to be reviewed and revised, 3) The alignment of learning standards with learning outcomes for Units 1-3 should be ensured, 4) Clear explanations regarding product marketing activities should be included, and 5) Illustrations and supplementary materials need to be added to each unit in accordance with the demands of core values, similar to those found in textbooks.

Reliability

The module's reliability can be determined when study participants can master the objectives and effectively follow the steps for each activity in the module at a satisfactory level. Most researchers suggest that an alpha coefficient greater than .8 indicates high reliability (Bogden & Milken, 2003; Sekaran & Bougie, 2010). Preliminary research results indicate that the Cronbach's Alpha values for all units within the module range from .74 to .88,

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with an overall Cronbach's Alpha value for the ECT module of .82. This demonstrates that the internal consistency of the developed ECT module as a whole is high.

Table 2
The Cronbach's Alpha value of the ECT Module

Unit	Unit within the module	Cronbach's Alpha
1	Face mask fabric	.88
2	Former face mask	.87
3	Face mask	.84
4	Hand wash soap	.77
5	Hand sanitizer	.86
6	Disinfectant wet wipes	.74
	Average	.83

Feasibility

To ensure this ECT Module's implementation in the TL for Form Four students, the researcher distributed a questionnaire to 20 Form Four science teachers. The teachers were asked to assess the feasibility level of the module by indicating their agreement level on a scale from one to five for aspects related to module activities, integration of SIA and DT, and overall assessment of the module. Table 3 presents the teachers' assessment of the feasibility of the module.

Table 3
Teacher Assessment of the Feasibility of the ECT Module

Unit	Feasibility Criteria	*M*
1	Activity implementation	4.65
2	Integration of SIA and DT	4.76
3	Overall module	4.71
	Average	4.71

Junus et al. (2021) stated that criteria with a minimum threshold of 3.50 indicate that the feasibility aspect of the module is acceptable. However, if the minimum threshold is below 3.50, changes need to be made as the feasibility aspect of the module is considered unsatisfactory. Overall, teachers provided assessments ranging from 4.65 to 4.76 for all three criteria related to the feasibility of the module. A minimum of 4.71 indicates that teachers agree that the ECT Module can be implemented in schools to foster ECT among Form Four students.

Effectiveness of the ECT Module

The Entrepreneurial Creative Thinking (ECT) Module was tested on 32 students in a rural secondary school in Tawau, Sabah. Students were given the Entrepreneurial Creative Thinking Test (ECTT) to assess their entrepreneurial creative thinking before and after the intervention using the ECT module. Inferential data analysis was conducted using paired samples t-test to determine whether there were significant differences between pre-test and post-test scores for the study subjects who underwent the SIA-DT intervention. Table 4 presents the results of the paired samples t-test analysis for the SIA-DT experimental group. The analysis indicates significant differences for pre-test and post-test scores in entrepreneurial creative thinking (t (31) = -20.605, $p < .05$), Investigation construct (t (31) = -12.175, $p < .05$), New Idea construct (t (31) = -13.373, $p < .05$), Design construct (t (31) = -13.638, $p < .05$), Create construct (t (31) = -15.033, $p < .05$), and Commercial construct (t (31) = -12.938, $p < .05$).

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Table 4
Results of the Independent Samples t-Test for the SIA-DT Experimental Group

Construct	Test	*M (SD)*	*MD (SD)*	*t*	*df*	*p*
ECT	Pre	11.59 (3.221)	-14.156 (3.886)	-20.605	31	< .05
	Post	25.75 (2.185)				
Investigation	Pre	2.47 (1.077)	-2.656 (1.234)	-12.175	31	< .05
	Post	5.13 (.707)				
New Idea	Pre	2.16 (1.139)	-3.031 (1.282)	-13.373	31	< .05
	Post	5.19 (.738)				
Design	Pre	2.13 (1.100)	-3.000 (1.244)	-13.638	31	< .05
	Post	5.13 (.707)				
Create	Pre	2.25 (.916)	-2.937 (1.105)	-15.033	31	< .05
	Post	5.19 (.738)				
Commercial	Pre	2.59 (.875)	-2.531 (1.107)	-12.938	31	< .05
	Post	5.13 (.707)				

Note: Significance level at $p = .05$

Table 5, on the other hand, presents the results of the Independent Samples t-Test analysis between the experimental group and the control group. The Levene's test for equality of variances was not significant for ECT ($p = .236$, $p > .05$), Investigation construct ($p = .171$, $p > .05$), New Idea construct ($p = .337$, $p > .05$), Design construct ($p = .129$, $p > .05$), Create construct ($p = .420$, $p > .05$), and Commercial construct ($p = .109$, $p > .05$), indicating that both the experimental and control groups have equal variances.

The analysis results indicate that the study subjects in the SIA-DT experimental group have significantly higher post-test scores compared to the control group in terms of the Entrepreneurial Creative Thinking (ECT) aspect ($t(62) = 21.962$, $p < .05$), Investigation construct ($t(62) = 9.390$, $p < .05$), New Idea construct ($t(62) = 13.904$, $p < .05$), Design construct ($t(62) = 11.988$, $p < .05$), Create construct ($t(62) = 16.812$, $p < .05$), and Commercial construct ($t(62) = 6.696$, $p < .05$). These results demonstrate that there is a significant difference in post-test scores for students in the SIA-DT group compared to the control group in terms of entrepreneurial creative thinking and all five constructs of entrepreneurial creative thinking.

Table 5
Results of the Independent Samples t-Test for the experimental Group and the Control Group

Construct	Experimental Group *M* *(SD)*	Control Group *M* *(SD)*	*MD* *(SD)*	*t*	*df*	*p*
ECT	25.75 (2.185)	14.25 (2.000)	11.500 (.524)	21.962	62	< .05
Investigation	5.13 (.707)	3.13 (.976)	2.000 (.213)	9.390	62	< .05
New Idea	5.19 (.738)	2.28 (.924)	2.906 (.209)	13.904	62	< .05
Design	5.13 (.707)	2.72 (.888)	2.406 (.201)	11.988	62	< .05

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Construct	Experimental Group *M* *(SD)*	Control Group *M* *(SD)*	*MD* *(SD)*	*t*	*df*	*p*
Create	5.19 (.738)	2.09 (.734)	3.094 (.184)	16.812	62	< .05
Commercial	5.13 (.707)	4.03 (.595)	1.094 (.163)	6.696	62	< .05

Discussion

This study aimed to assess the developed module for enhancing entrepreneurial creative thinking among Form Four students. The development of the ECT module was geared towards meeting the needs of students in the face of the Fourth Industrial Revolution. Assessments of its validity, reliability, feasibility, and effectiveness were analysed to ensure its feasibility in schools. The ECT module was constructed based on a clear and detailed theoretical framework, incorporating the Socio-scientific Issues Approach and the Design Thinking Model by integrating the Swartz and Parks Integration Model (1994) to examine the effects on the five constructs of Entrepreneurial Creative Thinking.

Overall, the study findings have demonstrated that the ECT module possesses good content validity and is feasible for enhancing entrepreneurial creative thinking among Form Four students. Analysis regarding the content validity of the module has shown that the three expert assessors well-received the ECT Module, with several improvements made to various aspects within the module. Reliability analysis indicates that the ECT module falls within an acceptable range based on Cronbach's alpha values. This study has confirmed that the integration of the Socio-scientific Issues Approach, Design Thinking Model, Swartz and Parks Integration Model (1994), entrepreneurial creative thinking model, and the ADDIE instructional design model verifies the legitimacy and reliability of the ECT Module for implementation in STEM-based pedagogical practices.

The results of the paired-sample t-test indicate that Form Four students in both the SIA-DT and control groups exhibited better performance in the five constructs of entrepreneurial science thinking in the post-test compared to the pre-test. However, Form Four students in the SIA-DT group demonstrated a significantly larger improvement in scores compared to their peers in the control learning group. This signifies that the opportunity to learn with the ECT teaching and learning module profoundly impacts the entrepreneurial creative thinking of Form Four students. As for the independent samples, t-test results suggest that using the ECT teaching and learning module effectively nurtures ECT and the five constructs of ECT.

Exposure to socio-scientific issues in the ECT module enables students to connect these issues with their personal experiences. Engaging in arguments about socio-scientific issues alongside inquiry encourages students to form preliminary ideas about the conceptualization of the product to be created, provides a clear understanding of the subsequent steps to take, and assists students in easily seeking answers to the issues or problems they encounter (Mutvei et al., 2017). Schmidt et al. (2013) emphasize that effective inquiry focuses on problem-solving rather than problem-finding. This is consistent with Fillis and Rentschler (2010), who assert that entrepreneurial creative thinking should prioritize the continuous creation of alternative solutions to address problems and identify new opportunities.

Furthermore, exposure to socio-scientific issues through the ECT Module aids in developing skills such as decision-making, evaluating statements, analysing evidence, and assessing various perspectives through discussions and debates (Sadler & Zeidler, 2005; Zeidler, 2016; Zeidler & Nichols, 2009) within the context of the real world. In this regard, students nurtured through SIA will be more adept at analysing and solving problems precisely. Moreover, the scientific knowledge generated through debating socio-scientific issues encourages students to generate ideas more effectively towards finding solutions to societal problems, thereby enhancing entrepreneurial thinking among students (Kinslow et al., 2017). Aligned with the socio-scientific issues addressed in each activity unit, these issues allow students to analyse and provide input, enabling them to create product innovations that address the issues raised.

Additionally, the increase in minimum scores among students participating in SIA-DT compared to control group can be elucidated through the highly detailed approach to socio-scientific issues (Topçu et al., 2018). In the initial phase of the socio-scientific issues approach, which engages students in issue-focused activities, students

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investigate the matters discussed within the issues. Subsequently, in the second phase involving connecting scientific ideas and relating to societal sensitivities, students pose questions among group members, link experiences to discoveries, acquire new knowledge, and establish connections between events or objects. The utilization of the socio-scientific issues approach, supported by the design thinking model, aids in enhancing students' entrepreneurial creative thinking levels. This is because the discussions surrounding socio-scientific issues lead to a step-by-step product generation process, as exposed by the design thinking model (Mutvei et al., 2019).

The integration of the socio-scientific issues approach with the design thinking model also encourages students to think outside the box and generate innovative ideas when seeking critical problem solutions (Aung et al., 2021). Therefore, design thinking can address ambiguous problems (Aung et al., 2021; Buchanan, 2001). Such problems can be effectively solved by employing high-level thinking skills. According to the revised Bloom's Taxonomy educational objectives (Anderson et al., 2001), design thinking encompasses all cognitive activities, including remembering, understanding, applying, analysing, evaluating, and creating (Powell & Kalina, 2009).

The degree of improvement in students' entrepreneurial creative thinking levels across all five constructs using the SIA-DT method as opposed to the conventional method is facilitated by the systematic integration of SIA and DT. Kinslow and Sadler (2018) and Sadler et al. (2017) also support that combining SIA with other instructional models enhances students' scientific knowledge as they explore socio-scientific issues. The debate of socio-scientific issues leads to discussions of ideas that expand scientific knowledge and its implications within society, ensuring deep understanding to make well-informed decisions. Consequently, SIA guides the appropriate decisions when selecting the best new ideas for further development into student-created products (Sadler & Zeidler, 2005; Zeidler, 2016; Zeidler & Nichols, 2009).

Indeed, implementing the ECT aims to cultivate creative entrepreneurs prepared to face the challenges they will encounter when designing and launching new ventures. Therefore, integrating the ECT into students' education through training and experiences in schools will produce students who can think entrepreneurially, identify market opportunities, and explore suitable ways to market the product (Bacigalupo et al., 2016). Students equipped with entrepreneurial creative thinking will consistently exhibit innovation in problem-solving (Nadelson et al., 2018). In other words, integrating the ECT into learning activities and instructional facilitation within the classroom can foster individuals capable of innovating and commercialising new ideas or products by leveraging existing opportunities.

Conclusions and Implications

This study confirms that the developed ECT teaching and learning module exhibits acceptable reliability and content validity. Overall, the ECT module is feasible to foster the entrepreneurial creative thinking among Form Four students. The study shows that the integration of the socio-scientific issues approach and design thinking model in developing the ECT module has effectively increased student entrepreneurial creative thinking. This study demonstrates that a carefully designed integrated approach for teaching ECT enables students to investigate the socio-scientific issues, generate new ideas, design, create and commercialize products in order to address the raised issues with the assistance of systematic steps within the design thinking model.

The present research findings draw the two implications for current STEM education practices. First, the existing STEM education usually adopts a particular teaching approach or model which cannot help promote the diversity and comprehensiveness of the STEM education to foster student's entrepreneurial creative thinking. Teachers should actively explore new integrated teaching approach to make the curriculum more meaningful to students. Second, teachers need continuous professional development to improve their ability to utilize new integrated teaching approach. Educational administrations should provide teachers with training and resource support and encourage them to innovate their teaching approach. At the same time, teachers need to upgrade themselves to better meet the demands of 21st Century education.

The future development of teaching and learning module requires the joint efforts of teachers, schools, and administrations to create a supportive atmosphere for innovations in integrated teaching approach to effectively stimulate students' entrepreneurial creative thinking in STEM education.

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Limitations and Future Research

This study has two limitations that provide avenues for future research in the assessment of the ECT Module. First, this study was a one-time study in the specific context of STEM education for Form Four students in two secondary schools. Therefore, the findings may not be applicable to different age groups. Second, the data analysis was based on the interpretation of the statistical results which lacked in-depth narrative evidence such as interviews to support the triangulation and coding results of classroom observations. As a result, future researchers are recommended to replicate the study in more diverse contexts; and to focus on a variety of empirical data, including observations, interviews, and document analyses.

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Declaration of Interest

The authors declare no competing interest.

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THE EFFECT OF OUTDOOR INQUIRY PROGRAM FOR LEARNING BIOLOGY USING DIGITAL TWIN TECHNOLOGY

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Abstract. *The outdoor inquiry has a significant meaning in learning biology, but it has a problem that is difficult to be frequently implemented in the school garden due to causes. On the other hand, alternative activities using the virtual world have been proposed, but due to a lack of reality and passive use, the continuity of the activities is low, and there are doubts about the effect on the affective domain. Therefore, this study developed a class program in which students directly construct a virtual world and explore living organisms using the digital twin platform. Also, researchers checked the changes in students' affective domain according to the application of the learning program. A teaching and learning strategy for learning biology was composed through the review of research and statistical analysis performed changes of the affective domain. The experimental group changed more positively than the control group in the affective domain of learning biology due to replicating the school garden so that living organisms can be explored indoors and outdoors. Consequently, class programs for learning biology can positively affect the learner's affective domain when it is provided with improved realism by digital twin, self-directedness, and autonomy to compare real space and object.*

Keywords: *affective domain, digital twin, learning biology, outdoor inquiry, school garden, virtual world*

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Introduction

In the 21st century, rapid digitalization has progressed throughout society, but changes in education have been slower than in other fields. In science education, there have been attempts to apply various digital technologies for effective learning from a convergence perspective, such as using the virtual world and artificial intelligence. Metaverse technology such as virtual and augmented reality have been applied to dangerous experiments, repetitive attempts or pilot tests, ecosystems in cyberspace, and museum experience programs. However, due to one-time activities that aroused interest, difficulties in applying to each school class due to technical barriers to entry, and negative perceptions of digitalization, it did not lead to significant changes or an overall paradigm shift.

On the other hand, the sudden COVID-19 pandemic has acted as a factor accelerating the digitization of the social system, including education, and has called for a radical paradigm shift in education (Fauville et al., 2021). It also served as an opportunity to reveal the digital infrastructure gap held by schools, the digital teaching and learning competency gap of teachers, and the digital literacy gap of students (Reimers, 2022). On the other hand, the change in the educational paradigm using Edutech enables time-space expansion of learning by continuously and actively utilizing advanced technology such as artificial intelligence and virtual reality in learning activities beyond the level of experience for simple interest (Holmes et al., 2019).

Post-pandemic education requires different learning methods in offline and online contexts, and expanding educational activities using virtual space presents new possibilities for science teaching and learning. In particular, learning biology has the new possibility of teaching and learning to utilize the virtual world online compared to other scientific education areas. Learning biology has successful learning effects when indoor and outdoor activities are carried out in parallel or together, and activities to observe and explore living organisms in a real natural environment are known to have various effects on learners' affective areas (Wells et al., 2015). It is generally agreed that providing outdoor inquiry activities is essential for learning biology, but the actual performing of outdoor activities is complex due to practi-

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cal limitations (Behrendt & Franklin, 2014; Dillon et al., 2006). In order to observe and explore various organisms outdoors, one needs help not only from experts or biological guides but also students must be able to use illustrations or auxiliary materials to expect the effect of inquiry learning outdoors. The physical collection has recently been limited for normative reasons and bioethics, and visiting time is limited due to the nature of the outdoors (Behrendt & Franklin, 2014).

Alternative learning activities using metaverse, such as indirect experience videos and virtual experience activities, are provided to compensate for this problem, but simply presenting digitized three-dimensional spaces has limitations in conveying diversity and reality in the real world. In addition, the high level of digital literacy and professional equipment required to create virtual spaces is another reason for the low utilization of metaverse technology in the educational field. Ultimately, the digital gap between students, teachers, and students can also affect bio-learning activities using the virtual world. Therefore, teachers should try to provide an alternative environment where students can freely continue to explore and learn about living organisms by overcoming the limitations of outdoor inquiry activities. Then, what is some alternative learning method to overcome various limitations like the digital divide in education using metaverse, and what teaching and learning strategies can enhance students' interest in learning biology and learning sustainability?

Digital Twin as an Alternative for Learning Biology Outdoor and Indoor

Recently, learning using the metaverse platform has been proposed as an alternative activity that can compensate for providing an interactive experience similar to reality (Dwivedi et al., 2022; Kuznetcova et al., 2019). Metaverse is generally used as a term for an environment in which one can interact and communicate with others in a virtual space. Generally, the metaverse can divide into four types; virtual reality (VR) creates a three-dimension space similar to reality, augmented reality (AR) can augment and possibly brings digital content to the real world, life-logging records and shares real-world data in digital space, and mirror-world moves the real world to virtual space (Tilak et al., 2020).

Among the types of the metaverse, virtual reality is a digital implementation of a similar space to the real world and has the advantage of providing a sense of immersion by interacting with content. In particular, it can provide a sense of space and freedom, so teachers or students can easily visit and experience places with spatiotemporal constraints in cyberspace. On the other hand, it is difficult for anyone to implement it quickly because virtual reality requires 3D rendering technology, and it is only possible to add or modify various contents if they are experts (Kelton, 2007; Suzuki et al., 2020).

The virtual world can provide a sense of immersion as a space that imitates the real world, but despite various advantages, the virtual world generated by prior VR technology does not reflect the real-world information equally, like length, width, and size (Tao et al., 2019). However, digital twin technology that implements real-world information equally in the virtual world is providing a solution to these deposits of virtual reality due to recent improvements in image processing hardware and artificial intelligence technology (Liu et al., 2021; Tao & Zhang, 2017).

The digital twin is a virtual replica that generates the same output value as a physical object for an input value and can define as an algorithm that describes a physical object's potential or actual components (Grieves & Vickers, 2017; Söderberg et al., 2017). The digital twin concept includes the components of an existing physical object, a replica of a virtual world, the transfer of data from a physical object to a virtual replica, and the flow of data from a virtual replica to a physical object (Thelen et al., 2022). The digital twin was proposed 20 years ago but was first implemented in 2011 to reproduce aircraft rescue behavior digitally (Tuegel et al., 2011), and has since been recognized as a method for product management and production in various fields and is now recognized as a significant high-tech technology leading the future industry (Lu et al., 2020).

The development of big data and artificial intelligence expands the range of digital twins and enables the construction of twins by digitally replicating physical entities, processes, and systems, such as living and inanimate objects. In addition, real-time monitoring is possible by improving the interconnection between real-world physical objects to share data with the goal of optimization and digital replicas in cyberspace (Rathore et al., 2021). The digital twin is a technology that enables innovative work, monitoring, diagnosis, and prediction in various fields, and its utilization in education is very high. In particular, in terms of mediating online learning and authentic learning, digital twins have the advantage of expanding opportunities for practice or hands-on learning to infinity (Rathore et al., 2021; Sepasgozar, 2020).

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Therefore, utilizing digital twin technology can overcome the limitations of one-time activities, passive experiences, and a lack of realism in outdoor learning biology using the metaverse. Furthermore, if the spaces and characteristics of living organisms in outdoor inquiry activities are replicated in the virtual world, continuous learning and monitoring can also be achievable indoors.

The Strategy of Metaverse Utilization for Learning Biology Outdoor and Indoor

In creative thinking, learning is effective when experiencing indoor learning activities for knowledge generation and understanding concepts and collaborative inquiry activities for practical experience (Pulgar, 2021; van der Zanden et al., 2020). Especially in the case of learning about living things, the learning effect is excellent when indoor and outdoor activities are combined, and activities of observation and exploration of living organisms in the natural environment are known to provide a positive effect on the learner's affective domain (Wells et al., 2015). Therefore, indoor and outdoor activities for learners should be necessary for the practical application of learning biology. However, some restrictions exist, like the lack of teachers' expertise in outdoor activities, the difficulty of on-site visiting, and the activity time constraints (Behrendt & Franklin, 2014; Dillon et al., 2006). New methods using virtual experience were suggested as alternative activities to overcome these problems shown during field trips. However, evaluating the use in the school field is inconsistent regarding continuity and effectiveness (Behrendt & Franklin, 2014).

After the COVID-19 pandemic, the metaverse expanded to everyday use in various fields, and the possibility of educational usage is newly emerging (Kuznetcova et al., 2019). These days, if the biology teacher can effectively apply the interactive learning method in the virtual world to the real world, they could exceed the spatial limit of learning activity. For example, the learning effect could improve on the class having spatial difficulty due to the limited activity places, such as exploring living organisms in the field.

Considering the utilization of the metaverse in the educational field, biology teachers should be able to build a virtual world quickly, and students should be able to operate various contents and functions of the metaverse. Also, teachers can save time and expand the activity space required for biology inquiry and learning through the metaverse. If teachers want to investigate and classify organisms in a convergent method using the metaverse, they could go outdoors with students to explore and collect them after the hands-on learning activity. For the construction of the virtual world, they should overcome various limitations, such as the selection of the inquiry site, the method of transportation, the presence or absence of target organisms, a preliminary survey of the visiting route on-site, damage to the ecosystem due to organism collection, and weather on D-day. Also, students and teachers in the virtual world could conduct social interactions between users and content.

Therefore, this new interaction method affects the learner's affective domain, like motivation, attitude, and task commitment (Akour et al., 2022; Stokel-Walker, 2022). Therefore, it is necessary to organize and utilize the virtual world for places teachers and students can quickly and frequently visit to combine learning biology indoors and outdoors easily. Also, it needs to consider the effect on students' affective domain in terms of teaching and learning and organize classes using the virtual world according to the school's situation and the student's characteristics.

Research Aim

It is essential to develop teaching and learning methods to guide the effective use of digital technology to respond appropriately to changes in the educational field, such as the increased possibility of activities in cyberspace due to the expansion of digital technology in education (Petrie, 2022; Vincent-Lancrin, 2022). Also, class activities with various digital technologies can provide customized learning opportunities in learners' problem-solving process experience by expanding learners' information search and utilization (Collins & Halverson, 2018; Yair et al., 2001). In this context, it has made challenging attempts to develop learning programs using advanced digital technologies such as artificial intelligence and the metaverse in various teaching areas. Also, recently with the development of AI technology, in the case of metaverse platforms, entry barriers to using innovative technologies using digital twin technology, a concept of replicating real-world spaces and objects to virtual spaces, are decreasing (Liu et al., 2021; Rathore et al., 2021).

If anyone can easily replicate real space in the virtual world with the development of artificial intelligence technology, teachers and students who do not have professional digital knowledge can implement the virtual world and effectively use it in classes. Then, how can anyone easily use the virtual world in their classes without

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professional knowledge as an alternative activity to overcome the limitations of outdoor activities in biology classes? Therefore, the researchers established the following research aims to address these questions.

First, it was intended to create a virtual world with a high sense of reality by using the digital twin and to organize a class program that allows students to learn biology. Students should be able to easily create the virtual world without using complex digital devices and technologies to solve the problem of high entry barriers in using the virtual world. In addition, to resolve the lack of reality, it is necessary to replicate the size of the space, the characteristics and size of the object, and the shape of the space. Therefore, researchers set the aim to create a virtual replica using a digital twin platform by simple digital devices in the school field and organize a class program that explores living things.

Second, it was organized into an experimental group and a control group to confirm the main effect and group effect to confirm the impact of the experience of digital twin classes on the student's affective area. Exploration of living things outdoors can affect the learning motivation and tendency to continue learning. However, the positive impact on students' affective areas is somewhat low or case-by-case due to low learner initiative and difficulty in solving professional problems. In addition, experience in learning biology using the virtual world also has a lower noticeable effect on the student's affective domain because of a low sense of reality and lack of interaction. Therefore, researchers set the goal to analyze the main effect of the experience of learning biology programs indoors and outdoors on the student's affective domain and the group effect of using digital twin technology.

Research Methodology

General Background

It can induce immersion in learning motivation and activities to students when learners are free to organize, control, and control objects in science experience activities using the virtual world (Dede et al., 2017; Psotka, 1995). In this context, it was intended to build a virtual world using a metaverse platform with digital twin technology replicating and manipulating the real world's space in cyberspace. In addition, students can freely explore any time and place when they can easily access living organisms outdoors (Subramaniam et al., 2018), and foster a positive attitude toward students' biological and ecological environment when outdoor experience activities are easy to access (Farmer et al., 2007). Therefore, the garden plant in the school was selected as a digital twin target as a place where data on the space corresponding to the physical object that is the target of the digital twin can be continuously obtained. This study set up research aims to clarify the utilization possibility and the effect of digital twin utilization learning programs on students' affective domain in biology class. Most of all, students must have the essential skill of digital literacy for generating and operating the digital twin, and they need to be taking the biology curriculum to inquire about living organisms. In addition, since it is necessary for anyone to easily create and operate a digital twin, high school students who freely handle digital devices such as smartphones and have basic knowledge of biology were selected as the subjects of the study.

Participants

From the perspective of creating digital twins, students need a certain level of digital device knowledge to acquire image data for virtual space construction self-directedly, adjust the location of virtual space in detail compared to physical space, and upload interactive content. In addition, basic knowledge of identification and classification is required for students to produce bio-related content to be presented in a virtual space. According to these needs, high school students in Korea aged 18 or older were recruited per this study's digital twin software policy. While most schools disagree with consistent classes using the digital twin, forty-four students studying at school A in South Korea participated in this study. The researcher received the school's official permission and students' voluntary research participation. Therefore, two classes in that school were recruited as application places to test research aims.

Forty-four students from a public school in Korea participated in class activities to replicate school garden spaces and organisms in digital spaces and to check the effect of learning biology programs on students' affective areas. All the students were taking 'Biology II' courses and completed the 'Biology I' course, which included a national curriculum on biology in Korea. Students were divided into different classes to ensure interaction and team activities in students' activities, and the students were divided into a plant classification program group and

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a plant classification class group using digital twin technology to check changes before and after the learning program experience.

The purpose and contents of the study were explained to all participating students before conducting the class program and pre-examination, and students submitted a voluntary participation agreement. The response to pre-test results was obtained by providing a survey paper to confirm changes in the affective domain before starting the first activity, and students' follow-up responses were obtained using the same survey after the last class activity. Among the students who responded, three were omitted from the analysis due to partially participating in the class for absence or some test questions. Therefore, the results of the pre-post response of twenty-one people in the control group who conducted plant classification classes and twenty people in the experimental group who conducted plant classification classes using digital twins were used for analysis.

An introductory survey was conducted during the pre-test period to confirm the individual metaverse experiences of the students who participated in the study (Table 1). All the students had experienced a metaverse, which was mainly divided into the first experiences in elementary or high school. 68.29% of students were experiencing metaverse in game type, while 31.71% of students were experiencing learning or other types. In response to the preference for metaverse, 73.17% said good, and no student said dislike. In addition, 56.1% of students frequently contacted a metaverse, and only 2.44% answered that they rarely contacted it. Therefore, most of the students in the study were familiar with the metaverse, and only a few had little contact with the metaverse. The school to which the students participated in the study belonged had a classroom equipped with three 360° cameras, eight laptops, and twenty-four tablet PCs as digital devices for use during class, and students had access to the wireless Internet. Also, all students carried smartphones and were available whenever necessary.

Table 1
The Ratio of Participant Characteristics of Metaverse

Experience period		Experience type		Preference		Contact frequency	
Answer	%	Answer	%	Answer	%	Answer	%
Elementary school	43.90	Game	68.29	Very good	43.90	Very often	19.51
Middle school	7.32	SNS	.00	Good	29.27	Often	36.59
High school	48.78	Learning	26.83	Moderate	21.95	Moderate	31.71
		Etc.	4.88	No so good	4.88	Occasional	9.76
				Dislike	.00	Rarely	2.44

Note. The ratio was calculated using the response results of 41 students finally used for data analysis and is a percentage of the ratio of the number of respondents to all respondents.

Construction of the Learning Program

Related prior studies were analyzed to develop project activities to explore plants living in school gardens using digital twin technology, and learning steps, strategies, and contents were presented. Plant objects placed in virtual spaces were searched and identified in advance for the list of plant species found in the actual school garden so that students could use them. The species and generic names of plants were presented based on the plant list of the National Institute of Biological Resources, and some species that were immature or could not be identified due to damage to plants were excluded.

In order to formation of the learning program in which students directly implement virtual spaces and experience inquiry activities, the learning process was decided through consideration of outdoor inquiry programs and creative problem-solving processes. In addition, teaching and learning strategies and learning contents were presented using the characteristics of the metaverse platform to give students the degree of freedom to lead activities and interactions. To construct a plant inquiry learning program using digital twin technology, various research

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related to scientific problem-solving processes and social interaction were analyzed, and teaching and learning strategies were derived by considering outdoor experience activities and research related to the educational use of the metaverse.

The scientific inquiry resulted from modeling scientists' problem-solving processes from the learning perspective (NRC, 2000). Also, the scientific problem-solving process can be divided into the discovery context to generate explanatory knowledge and the verification context to confirm the suitability of the generated knowledge (Klaur et al., 2002). In the cognitive constructivist perspective, problem-solving processes can be divided into problem definition and information discovery, searching for solutions to reach goals, generating and evaluating solutions, explaining problem-solving status, and value judgment through communication (Wang & Chiew, 2010). From this perspective, NSES suggests that the scientific inquiry process in science classes consists of question definitions from current knowledge, brief explanations or hypotheses, simple investigation planning and composition, evidence-based explanations, consideration of other explanations, delivery of explanations, and verification of explanations (NRC, 2000). Therefore, scientific inquiry activities can be divided into the discovery of scientific problems, tentative explanations, and verification of tentative explanations of discovered problems. The discovery process includes exploration and generation of information or inquiry problems provided to learners; the verification process includes evaluation and explanation of solutions, and recognition of value judgment and communication on inquiry results.

The plant's inquiry learning process outdoors is generally divided into before outdoor activity, outdoor activities, and after outdoor activity (Braund & Reiss, 2004). On the other hand, inquiry activities in virtual space present detailed learning steps such as scientific observation and classification, learning biology, pre-survey, in-virtual space exploration, and post-virtual activity organization (Rowe & Humphries, 2004; Subramaniam et al., 2018). In addition, it is necessary to construct a relationship between the virtual space and the outdoor activity of plants for effective learning (Potkonjak et al., 2016). According to these discussions, plant inquiry using the digital twin can consist of discovering a problem or object on scientific inquiry, exploring digital twin technology for scientific inquiry, generating the digital twin about outdoor space, and applying scientific inquiry activity.

The discovery step corresponds to the preparation process for outdoor exploration and digital twin data collection of plants living in the school garden. In particular, this step is the process of discovering problems or objects on scientific inquiry, and students directly establish plans for outdoor inquiry and learn basic knowledge for plant observation and identification indoors. Regarding preparation for outdoor plant inquiry, it includes information on search paths, habitable plants, and investigation methods in the school garden. Also, regarding digital twin data acquisition, available camera tools, filming methods, and filming locations are set in advance. Students are allocated to team members who individually contribute to each task for convergent problem-solving that shares the same goal in collaborative activities.

The exploration step corresponds to plant exploration and data acquisition of digital twin outdoors according to the plan established in the previous step. The students discover and identify plants in the school garden following the plan, including exploration routes and methods, and record the plants' characteristics using mobile devices. At that time, three-dimensional spatial photography for digital twin data acquisition is performed, and image correction is practiced if real-time correction is required about image data. If an error in direction or position occurs after acquiring a three-dimensional image, the immediate correction is more effective for digital twin generation than post-correction. Team activities like finding and identifying plants and taking and correcting three-dimensional spatial images consist of a divergent problem-solving process for focusing on individually assigned tasks for outdoor inquiry.

The generation step is exploring digital twin technology students will use to solve scientific problems and create the digital twin themselves. According to cognitive constructivist perspectives, cognitively structured experiences correspond to essential learning factors (Matthews, 2000). In addition, learning activities using the virtual world can improve learning motivation and induce immersion in activities when learners are free to directly adjust and control objects (Dede et al., 1999; Psotka, 1995). From this point of view, the main activity of the student is operating the software to correct and create virtual space. Artificial intelligence in the platform automatically creates a 3D digital twin of a school garden when the 3D spatial image data taken in the previous step is uploaded to the cloud through the app or web page.

Anyone can easily create a 3D space, but detecting intentional and unintentional biases contained in spatial data and correcting and supplementing it must be performed to prevent distorted results in processing data using artificial intelligence (Akter et al., 2021; Byrne, 2021). Therefore, the broad scanning of the created virtual space using a mini-map and sky view function to correct image data is performed for discrimination, whether distortion

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or errors in space. Also, the structure of the space, the description of the characteristics of the plant, excluding the shape and location of the plant, and additional photos, videos, web links, Etc., should be added directly by the student using the tag function. In addition, virtual tour functions can be used in digital twins, so students can plan and organize virtual tour orders and content to share results with others. Therefore, this step composes divergent problem-solving activities with individual goals to organize data, such as creating interactive content, explanations, and observation resulting in the created 3D digital twin space.

The application step is a communication process that announces plants living in the school garden using digital twins and shares virtual tours for plant introduction creatively organized by student groups. The advantage of education using the virtual world is that it shows multiple accessibility and invisibleness (Carvajal et al., 2020), and it is necessary to provide a sense of reality by providing interchange opportunities that deal with the virtual and real world at the same time for practical educational effects (Potkonjak et al., 2016). Therefore, students must present and share the results by group using the results of plant exploration conducted in the exploration stage and the data attached to the digital twin space in the creation stage.

During this process, students create URL links that access digital twins, provide virtual tour functions, and share them with students so that other students can experience and compare individual virtual and real worlds. In addition, from the perspective of developing students' creative thinking and transferring learning, investigating plant images establishes and presents by utilizing the advantages of digital twins for school gardens. For example, the measurement function provided by the digital twin platform can be used to measure the height of trees, the expansion width of tree branches, the distribution area of certain plant species, and the speed of expansion of plant species habitats over time in cm.

Unlike the experimental group, the control group, which does not use Digital Twin, uses the results to produce information on plants and exploration methods living in the school garden using digital collaboration tools such as cloud document tools and presentation production tools and present and communicate by the team. Therefore, both groups are active in the same area and plant species, but the experimental group introduces the results of the inquiry through the implementation of the virtual world, and the control group presents the results as a presentation (Table 2).

Table 2
Learning Content and Method between Experimental Group and Contrary Group

Learning step	Experimental group	Control group
Discovery	· Basic knowledge learning for plant observation and identification · Planning of plant exploration outdoor activities · Setting observation paths and methods for plants in the school garden · Camera preparation for spatial image acquisition · Setting the method and the point of 3D image acquisition	· Basic knowledge learning for plant observation and identification · Planning of outdoor plant exploration activities · Set searching paths and observation methods for habitable plants
Exploration	· Exploration of plants according to the inquiry plan · Observation and recording of the plant features with a mobile device · The identification of found plants (using assistant AI and mini-illustration book) · The Acquisition of the 3D image and calibration by mobile device	· Exploration of plants according to the inquiry plan · Observation and recording of the plant features with a mobile device · The identification of found plants (using assistant AI and mini-illustration book)
Generation	· Operation of the digital twin platform and authoring app · Uploading of 3D images to the cloud and Generation of the digital twin as the virtual space · Checking and correcting distortion or error in space image · Adding tags in virtual space (plant feature description, photos, images, web links, Etc.) · Organization and presentation of the virtual tour of each group	· Determination of how to present the results of plant exploration · Generation of the presentation contents (descriptions, photos, and clips of the plant) · Exhibition of boards, infographics, Etc, about inquiry results.
Application	· Sharing of the digital twin URL links · Introduction of the virtual tour created by each team · Presentation of plants living in the school garden using digital twin · Presentation of ideas of plant inquiry when applying the digital twin · Self-assessment and peer review among teams	· Introduction of presentation materials produced by teams · Presentation of plants living in the school garden · Presentation of ideas for another plant inquiry · Self-assessment and peer review among teams

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Application of the Learning Program

New innovative technologies can spread quickly through networks, but the personal gap in utilizing technology is so large that simplification and guidance in the methodological aspects of utilizing technology are needed (Reimers, 2022). Using advanced technologies in science classes should focus on instrumental use for the efficiency of interactive learning rather than on us as a purpose (Chen et al., 2020; Guan et al., 2020), and providing learners with an experience of taking the lead can have a positive impact on the defining area of learning (Dede et al., 2017).

It is necessary to check how it affects students by confirming the degree of change in affective areas such as learning motivation, task obsession, and learning attitude of students who have experienced classes in teaching and learning programs developed according to this perspective. To this end, six classes per two hours were organized to be provided to student groups participating in plant inquiry learning programs using digital twins and classes to be provided to student groups participating in general plant inquiry classes. Two science education experts and four biology teachers were asked to review the validity of the class guidance plan, including the learning process and strategy of the class program, and the content validity index (CVI) was 94%, confirming that it was an appropriate composition.

A total of 12 hours of classes were conducted in the experimental and control groups, and 3 hours were conducted for each stage according to the class stage leading to discovery, exploration, generation, and application. The artificial intelligence app, which will be used to explore plants in outdoor activities, is installed on all students' smartphones before class to be used immediately as soon as the activity begins. In the case of the experimental group, to save time in creating a digital twin, all devices were prepared in advance to use the school's tablet pc and 360° camera. All students freely used the tablet PC provided by the school and used a laptop for team activities.

Generation and Operation of Digital Twin

The generation of the digital twin was performed using Matterport App (Matterport Inc.) to construct a virtual school garden space for students. Among various metaverse platforms that use digital twin technology, it is easy for users to access and operate for virtual reality generation, and it can be implemented just on mobile phones (Ramakrishnan et al., 2021; Sulaiman et al., 2020). Above all, digital twin technology through artificial intelligence can accurately express the size and location of objects or spaces present, even if it is highly realistic because it can be measured in cm. In addition, teachers or students can add content in the virtual world by tagging interactive content such as text, images, and videos, and various functional software like machine learning artificial intelligence can be called and used through a link to a web page.

VR platforms such as Google Street can create virtual spaces, but an additional program must use to replicate real-world objects in the cyber world through digital twins. On the other hand, it is optimized for quickly creating digital twins for buildings in virtual space. Outdoor environments can replicate if buildings, walls, columns, and trees can be used as a reference point for accurately recognizing surrounding objects. In addition, when the user uploads a 3D scan image of a target space aimed to replicate to the web cloud, artificial intelligence automatically configures an optimized replication space. Above all, the fact that 3D scanning taken with mobile phones and 3D cameras can quickly be composed in three dimensions increases educational utilization. In addition, users can attach text, images, videos, and web links in the replicated virtual space using the VR interface, and collaboration activities are possible through various functions.

The user needs to create an account for a free digital twin space, and he could use multiple spaces and user accounts by subscription. Even if it is possible to post the 3D space to other people by providing a link to a space, a paid subscription could be required to edit the many spaces simultaneously. It would help if students prepared a camera or mobile phone to shoot target space to compose a digital twin space. However, a 360° camera can use an existing camera to capture, and it is also possible through the camera of a mobile phone can install the app. If the user uploads the 2D Capture images of the target space to the web cloud, then automatically constructed into 3D digital twins through AI. Therefore, students need not study and train in the knowledge of VR construction. The artificial neural network deep learning model for the digital twin can be used without separate payment; when the number of captured images increases, the time required to check the results can be longer. When using a mobile phone, the position to focus on is displayed when capturing space in place so that students can hold it with their hand and shoot, but a tripod is required to use a 360° camera (Figure 1).

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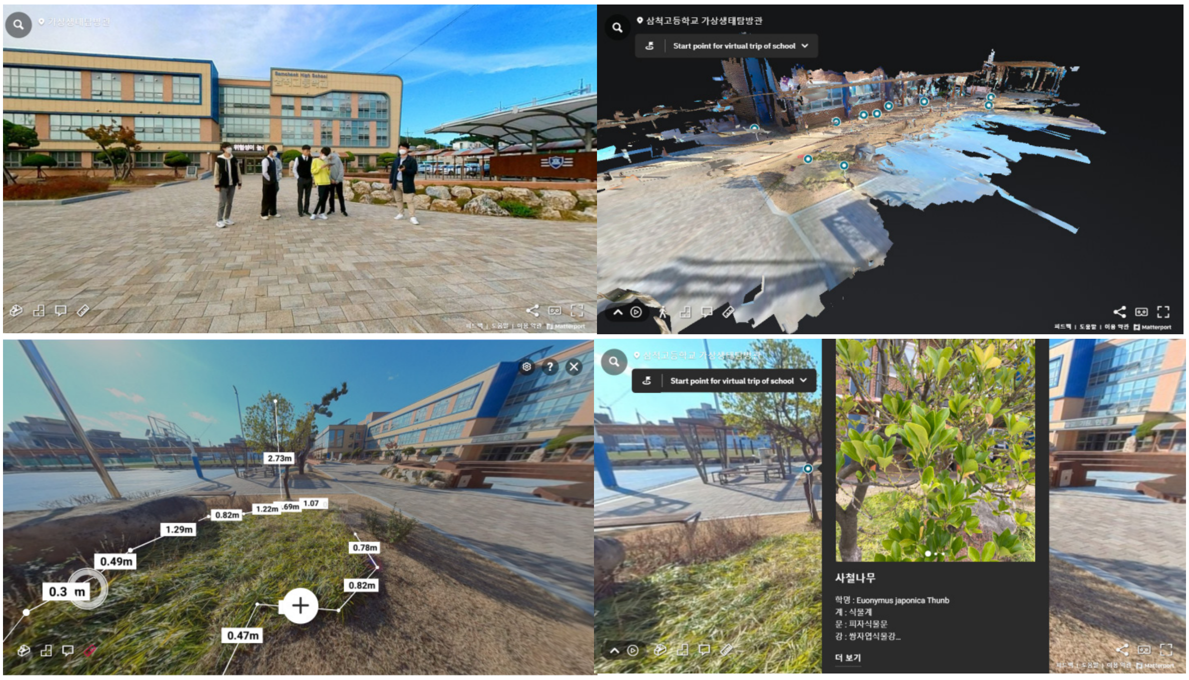
Figure 1
Example of Students' Virtual Activity Using Digital Twin App



Note. 1) The teacher and students go outdoors to observe, investigate, and identify the plants in the school garden. 2) After the cloud upload 360° spatial data through a mobile device, students can automatically create a digital twin for the school garden. 3) Students can edit the space through an app on a mobile device to operate multi-function; start location, labeling, guide tour, tagging, memo, privacy blur, multi-view, and trimming. 4) Students can measure the length, width, and area of tall trees or plant communities that are difficult to measure and freely use the tagging function to post plant characteristics and ecological features found during the investigation.

Measurement of Effect on Affective Domain

Experience in a new form of learning program using digital technology has a positive effect on the level of motivation related to student participation (Akour et al., 2022; Stokel-Walker, 2022), and experience activities about the nature environment can affect attitudes and learning biology (Ayotte-Beaudet et al., 2017; Wells et al., 2015). Factors that should be considered for measuring students' affective domain changes are the level of motivation, the intention to participate in learning, the attitude to participate in learning, and the task commitment to continue learning (Foronda et al., 2017; Makhija et al., 2018). Attitudes to participate in learning to reflect positive or negative perceptions of learning that students are currently performing, and task commitment can provide information on the tendency to immerse and continue learning activities they are participating in (Farmer et al., 2007; Kasperiuniene et al., 2016).

In this context, the learning motivation test (Keller, 2009) was used to measure the changes in the affective domain in learning biology, and researchers checked sub-factors changes; attention, relevance, confidence, and satisfaction. The questions for each sub-factor include some reverse questions, including twelve attention-focused questions, nine relevance questions, nine confidence questions, and six satisfaction questions. The combined result of the question response corresponds to the level of motivation for learning activities. Cronbach'α was very high at .91, as a result of calculating by putting it into 20 independent students to confirm the internal reliability of the test paper translated into Korean. 21-question learning attitude test (Byeon, 2022) was used to confirm the change in students' attitudes toward biology. The test uses positive and negative words as extremes and contains reverse questions to prevent random answers. In addition, a task-commitment test (Byeon, 2022) consisting of 25 questions was used to confirm the tendency to continue learning biology activities.

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Analysis of Effect on Affective Domain

Students responded online before the first class and immediately after the end of the last class to each survey. After response data collection, the response results were statistically analyzed to confirm the effect of applying the learning program before and after the classes between the experimental group and the control group. Learning disposition was presented before the learning motivation, learning attitude, and task commitment test for learning biology, and the results of the pre-post response of each test paper calculated the average value and performed variance analysis. In addition, a chi-square test was conducted on metaverse and learning biology-related tendencies to determine whether there are differences in student factors that can affect the group effect.

It is necessary to confirm the main effects of the experience of indoor and outdoor parallel biology class programs conducted by both groups on students' affective domain to analyze the effect of classes conducted on student groups in this study. Therefore, a linear regression analysis was conducted by setting the group of students participating in the class activities as dummy variables for the main effect analysis and setting the pre-test results as independent variables and the post-results as dependent variables. Afterward, the group effect was confirmed by conducting a one-way distributed analysis of learning motivation, learning attitude, and task obsession using the group as a factor to confirm the effect of the class program applied independently to each group on the affective area.

Research Results

Learning Disposition of the Metaverse and Biology

It is necessary to analyze students' learning tendencies of biology and the metaverse before confirming the effect of the application of the class program on students. Therefore, independent samples t-tests were conducted using student responses to the interest, the awareness of the importance, and the preference of related occupation of the metaverse and biology learning (Table 3).

Table 3
Learning Disposition Difference Between Two Groups

Learning disposition	*EG*		*CG*		*t*	*p*
	M	*SD*	*M*	*SD*		
Interest in the metaverse learning	4.35	.75	4.00	.95	-1.309	.920
Awareness of the importance of the metaverse learning	4.10	.85	3.71	.96	-1.361	.735
Preference for the metaverse-related occupation	3.40	1.05	2.57	1.21	-2.343	.341
Interest in the biology learning	4.05	.945	3.90	1.04	-.466	.312
Awareness of the importance of the biology learning	3.90	1.02	3.86	1.01	-.135	.901
Preference for the biology-related occupation	3.00	1.23	2.95	1.28	-.126	.179

Note. EG = experimental group, CG = control group.

There was no significant difference in the analysis results of students' responses on the learning propensity and interest in the metaverse and biology learning between the experimental and control groups. Therefore, it was necessary to identify individual factors that may affect participation in the learning program developed in this study. According to the result of the chi-square test conducted to check the effect of student factor, it was following for the presence or absence of experience in the metaverse learning $\chi^2 = 1.003$, $df = 1$, $p = .317$, and as a result of the mainly used metaverse type $\chi^2 = 3.864$, $df = 4$, $p = .425$. In addition, the chi-square test results for the acquisition method of the metaverse information were $\chi^2 = 6.113$, $df = 5$, $p = .295$, and the results for the contact frequency of the metaverse information were $\chi^2 = 2.621$, $df = 4$, $p = .623$. The acquisition method of the biology information was $\chi^2 = 3.578$, $df = 3$, $p = .311$, and the analysis results for the contact frequency of biology information were $\chi^2 = .739$, $df = 4$, $p = .946$. Therefore, there was no difference in the group regarding the metaverse and

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biology experiences and information between the experimental and control group students. Therefore, it can be regarded as a homogeneous group with little difference between the experimental and control groups in the metaverse and biology learning context.

Main Effect of the Application of the Learning Program

It is necessary first to check the main effect of whether the indoor and outdoor parallel class program applied to the experimental group and the control group causes a change in the affective domain of learning biology to analyze the group effect of digital twin application. The main effect analysis was conducted through linear regression analysis of 41 students in the two groups' biological learning motivation, learning attitude, and task-obsession test results before and after class. As a result of conducting a linear regression analysis using the group as a dummy variable and setting the pre-test result as an independent variable and the post-test result as a dependent variable, the variance analysis results for the generated model were statistically significant (Table 4).

Table 4
The Regression Model on the Student's Affective Domain

Model	Estimate	*SE*	95% CI		*p*
			LL	*UL*	
Learning motivation [a]	.864	.108	.645	1.083	<.001
Learning attitude [b]	.627	.107	.409	.844	<.001
Task commitment [c]	.971	.123	.721	1.220	<.001

Note. Total N = 41. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.
[a] Dependent variable = post motivation, R^2 = .678. [b] Dependent variable = post attitude, R^2 = .560. [c] Dependent variable = post task commitment, R^2 = .672.

According to the affective area's pre and post-test results according to the application of classes by group, learning motivation increased from pre-result (M = 122.83, SD = 17.46) to post-result (M = 143.05, SD = 20.53). In addition, the learning attitude increased from pre result (M = 87.22, SD = 12.02) to post result (M = 97.93, SD = 11.82), and the task commitment increased from pre result (M = 88.98, SD = 10.25) to post result (M = 100.71, SD = 13.47). Through the main effect analysis results, the increase in the level of the affective domain after class was statistically significant compared to before the class program was applied in this study. Therefore, it can be interpreted that the experience of the indoor and outdoor combined biology inquiry class positively affects students' motivation, attitude, and task commitment to learning biology.

The regression model coefficients derived from the analysis showed significant pre-test to post-test, so it can be interpreted that both groups have main effects from the application of indoor and outdoor parallel classes. In addition, since the group variable was found to be statistically significant, it was confirmed that there was a difference in effects according to the group (Table 5).

Table 5
Coefficient of Model about The Change of Student's Affective Domain

Measurement	Model	*B*	*SE*	*β*	*t*	*p*
Learning motivation	Group	-14.002	3.738	-.345	-3.745	.001
	Learning motivation	.864	.108	.735	7.972	<.001
Learning attitude	Group	-6.969	2.553	-.298	-2.730	.01
	Learning attitude	.627	.107	.637	5.831	<.001
Task commitment	Group	-7.146	2.498	-.268	-2.861	.007
	Task commitment	.971	.123	.738	7.870	<.001

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Group Effect by the Application of Learning Program

This study developed a learning program using digital twin technology so teachers and students can easily explore outdoor plants and have various interactive experiences. In addition, students were divided into an experimental group and a control group to confirm the impact of the developed learning program on students were applied. The learning program using a digital twin was applied to the experimental group, and a program without a Digital twin was applied to the control group to confirm the group effect. The average for each group was calculated by conducting the test of students' affective domain according to the experience of the teaching and learning program of the experimental group and the control group (Table 6).

Table 6
Mean of Pre-test and Post-test for Affective Domain between Students Groups

Measurement		Experimental group				Control group			
		Pre-test		Post-test		Pre-test		Post-test	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Motivation of learning biology		123.50	16.58	150.80	17.83	122.19	18.64	135.67	20.58
Sub-factor	Attention	42.80	5.29	51.85	6.53	42.57	6.28	47.05	6.96
	Relevance	32.00	4.41	38.30	5.12	30.76	4.93	34.62	5.56
	Confidence	26.85	5.62	33.75	5.21	27.57	5.33	30.38	5.78
	Satisfaction	21.85	2.89	26.90	3.01	21.29	3.91	23.62	3.67
Attitude of learning biology		89.30	13.96	102.80	10.47	85.24	9.77	93.29	11.37
Task commitment of learning biology		90.40	9.78	105.75	11.04	87.62	10.74	95.90	14.06

The mean of the experimental group's post-test results increased more than the pre-test results on the motivation for learning biology at 27.30, while the mean of the comparison group's result increased to 13.48. For both groups, the mean of the post-test results was higher than the pre-test results, confirming that the instructional program applied to the students could positively affect the affective domain. Therefore, the change in each sub-factor of the motivation was calculated in detail to confirm the cause of the difference in the level of motivation for learning biology between the two groups. The experimental group's mean change of attention factor was higher at 9.05 than the control group's change of 4.48, and in the relevance factor, the experimental group's mean change was higher at 6.30 than the control group's 3.86. In addition, the confidence factor change was higher in the experimental group, 6.90, than in the control group, 2.81. The change of satisfaction factor in the experimental group at 5.05 was higher than control group at 2.33. In the overall factor of motivation, it indicated a relatively high increase in the experimental group's mean.

In addition to learning motivation, the mean change in the experimental and control groups for attitude and task commitment of learning biology was calculated. The mean of the attitude of learning biology in the experimental group increased to 13.50, higher than the control group's change of 8.05. In addition, the experimental group's mean change of task commitment of learning biology was higher at 15.35 than the control group's change of 8.29.

In both the experimental and control groups, the post-test results increased compared to the pre-test results. These changes can be interpreted as an increase in students' positive perception and tendency to continue learning about biology, including learning motivation, due to the experience of direct inquiry activities in the natural environment and learner-led activities. On the other hand, the fact that the change in the experimental group was more significant than that of the control group can be interpreted as positively affecting the sub-elements of learning motivation by creating, manipulating, and controlling the virtual world directly through digital twins. In addition, positive perception and continuity of learning biology were relatively increased due to students' participation and immersion increased using a new digital technology called Digital Twin.

In both groups, the post-test results about the motivation of learning biology were higher than the pre-results, and the average for each detailed area also increased significantly afterward. In other words, it means that both

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the experimental and control groups can positively change their motivation for learning biology through the experience of biology teaching and learning programs for plant exploration. In addition, the experimental and the control groups showed higher post-test results than the pre-test results on the attitude and task commitment of learning biology, so the teaching and learning programs experienced by students can positively affect learning biology attitudes and task commitment. Also, since the change in the experimental group was more significant than the control group, the experience of classes using digital twins could be positive for students' learning motivation, perception of biology, and intention to continue learning. Therefore, One-way ANOVA was conducted to confirm whether these effects were statistically significant (Table 7).

Table 7
One-way ANOVA for the Change of Students' Motivation for Learning Biology

Measurement			*SS*	*df*	*MS*	*F*	*p*
Motivation of learning biology		Between group	10744.590	3	3581.530	10.468	<.001
		Within group	26688.105	78	342.155		
Sub-factor	Attention	Between group	1159.045	3	386.348	9.722	<.001
		Within group	3099.845	78	39.742		
	Relevance	Between group	677.050	3	225.683	8.922	<.001
		Within group	1972.962	78	25.294		
	Confidence	Between group	594.885	3	198.295	6.575	.001
		Within group	2352.395	78	30.159		
	Satisfaction	Between group	387.924	3	129.308	11.138	<.001
		Within group	905.588	78	11.610		
Attitude of learning biology		Between group	3446.566	3	1148.855	8.721	<.001
		Within group	10275.495	78	131.737		
Task commitment of learning biology		Between group	3893.627	3	1297.876	9.742	<.001
		Within group	10391.312	78	133.222		

Note. SS = Sum of square, MS = Mean of square.

According to the result of ANOVA, motivation of learning biology and sub-factors showed that the post-test results in both groups increased statistically significantly compared to the pre-test, and there were also differences between groups. In other words, it means that the change in the pre-and post-test results of the experimental group increased at a significant level compared to the control group. Accordingly, the effect size within the group was calculated using the pre and post-test results to confirm the effectiveness of the class program applied in this study on learning motivation.

The effect size on the experimental group was Cohen's d = 1.238, and Cohen's d = .936 in the control group, and both groups showed an effect size of a high level of learning motivation. Therefore, the biology class program applied to both groups positively affected the motivation of learning biology within groups. Consequently, experiencing outdoor life exploration classes that cross indoor and outdoor can improve students' attention, relevance, confidence, and satisfaction with biological learning and positively affect changes in learning motivation.

The statistical analysis of variance in the attitudes and the task commitment for learning biology showed that the post-test results in both groups increased significantly compared to the pre-test results, and differences between groups existed. These results mean a statistically significant difference in the attitude toward learning biology of the experimental group and the change in task commitment for learning biology compared to the change in the control group. Accordingly, the effect size within the group was calculated to confirm the effect of the class program applied in this study on the attitude and task commitment to learning biology.

As a result of calculating the effect size using the pre and post-test of the two groups, the effect size about the attitude of learning biology within the experimental group was Cohen's d = 1.094, and the comparison group was Cohen's d = .759, showing a very high-level effect. In addition, Cohen's d was calculated using the results of the task commitment test for learning biology, the experimental group was Cohen's d = 1.472, and the control group was Cohen's d = .662, indicating that the teaching and learning program at each group effectively improved task commitment. Consequently, the biology class program applied to both groups positively affects students' affective domain.

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Since it has been confirmed that the effect size of the class applied to the group is significant, it is necessary to statistically check whether there is a difference in the degree to which the class applied to each group provides a positive effect on the students' affective domain. Therefore, to confirm the effect size of the class program applied independently to the two groups, the partial eta square value was calculated using the pre-test result as a covariate and the post-test result as a dependent variable. The partial eta square value of the learning motivation for learning biology was $\eta^2 = .270$, and the group effect size was very high. Therefore, analyzing the differences between groups and the effect size confirmed that the experimental group could induce a much more positive effect than the control group. Also, the partial eta square value about the attitude of learning biology was $\eta^2 = .164$, and the task commitment of learning biology was $\eta^2 = .177$. Therefore, it confirmed that the experimental group could induce a much more positive effect on the attitude and task commitment than the control group according to the analysis results of the differences between groups and the effect size.

In conclusion, affective areas such as learning motivation, attitude, and task obsession for learning biology changed significantly in the control group that applied learners' self-directedness and indoor and outdoor life exploration classes. Digital twin classes were more positive in the experimental group than in the control group.

Discussion

Exploring various organisms outdoors is essential for learning biology, offering advantages that indoor activities cannot provide. However, outdoor activities for teachers come with limitations in the real world. As a result, virtual reality technology, which transports exploration sites to virtual spaces, has been proposed as a way to learn about organisms. With the advancement of digital technology, the potential for the educational use of the metaverse is growing. However, successful learning becomes possible only when effective teaching and learning strategies are employed to properly utilize these technologies for scientific education (OECD, 2022). From this perspective, this study presents the following considerations for using virtual reality in learning.

First, the virtual world should be constructed so that students can feel more realistic. Traditional virtual reality learning activities require professional skills because they rely on computer graphics implemented through rendering, so some users feel less realistic (Cobb, 2009; Garrison, 2016). In addition, from the student's point of view, virtual world control is complex and requires passive use, reducing the opportunity for interaction, which can negatively affect the affective domain (Fauville et al., 2021; Nadler, 2020). On the other hand, the more similar the virtual environment is to reality, the more realistic students perceive the virtual space, and the more effective learning experience can be induced (Kwon, 2020). Therefore, to use immersive virtual space for learning, it needs to provide the same level of space and experience as possible. Unlike the rendering-based space generation method using computer graphics programs, this study maximized the sense of reality by replicating real space and objects using a digital twin platform that constructs space with artificial intelligence through 3D photography. It was shown that there was a very high level of effect in the affective domain change of the experimental group participating in this study, and the effect on the level of learning motivation and task commitment was greater than that of the control group. These results can be attributed to the fact that students could measure and interact with the actual size of objects and spaces in the virtual space in the experimental group that provided the exact size and shape of 3D space, objects, and locations reflecting depth and distance.

Second, it is necessary to provide freedom for learners to organize the virtual world and interact with various interactions easily. The level of motivation for learning participation may vary depending on the degree of freedom given in learning activities and the initiative of activities, and motivation for learning participation is the driving force for continuing learning (Karatas et al., 2017). In particular, in science learning activities, providing learners with self-directedness and freedom can positively affect learning motivation and learning (Dede et al., 2017). In addition, learning participation attitudes reflect students' positive or negative perceptions of the learning they are currently performing, and task commitment can provide information on their tendency to immerse themselves in and continue their learning activities (Farmer et al., 2007; Kasperiuniene et al., 2016). Unlike activities that only utilize passively provided virtual reality, this study provided the initiative for experimental group students to directly create digital twins in the virtual world and use them by adding various interaction objects. In addition, students can immediately check and compare with the real one in the school garden during the action in a virtual reality space, and it can arise to form a positive perception of living things. The experimental group's results that created and utilized the digital twin themselves showed that providing students with a degree of freedom through a change in attitude toward learning biology and task commitment was necessary.

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Summarizing the above discussions, using the virtual world as an alternative to outdoor biology inquiry activities can lead to learners' motivation to participate, a positive perception, and a tendency to continue learning biology when learners can construct and interact freely. To this end, various digital twin platforms should be provided so anyone can easily construct and operate a realistic virtual space. It is very encouraging that the effect on the affective domain of the experimental group that experienced digital twin-based exploratory learning activities in this study is more favorable than the control group, which means that indoor and outdoor exploratory activities linked to the virtual world can be effective in changing students' perception of actual learning biology.

Conclusions and Implications

This study used digital twins to create a realistic virtual world, apply it to outdoor inquiry classes, and investigate the effect on students' affective areas. Researchers could present several conclusions and implications based on various research findings and discussions.

First, an outdoor inquiry class for learning biology using the virtual world with a high sense of reality using digital twins was able to organize. Ironically, the biggest problem in learning using the virtual world is its unrealism. In other words, learners who are users must passively consume the virtual space that developers provide. Even images perceived in the real world, different levels of graphic space, and limitations that cannot be compared to the real world reduce students' sense of presence. However, in this study, the digital twin platform allowed students to create virtual replication spaces in school gardens with simple digital devices and compare them to the real world. Therefore, this study confirmed the possibility of implementing hybrid learning that can be converged between the real world and the virtual world, which is aimed at the educational environment of the future digital society.

Second, providing students with a sense of realism and initiative in activities can positively affect learning biology in the real world through virtual world activities. Another problem in learning using virtual reality is passivity and isolation. Virtual spaces created by experts cannot be expanded or modified by users, and new content can be added only by developers. However, the digital twin platform allows anyone to modify or update virtual spaces by sharing and adding content. In addition, team activities can resolve individual isolation caused by learning using virtual reality, and interactions between virtual and real worlds increase opportunities for interaction between humans. Increasing learners' initiative and interaction can positively affect the motivation, perception, and learning continuity of learning biology about the real world through virtual world activities.

In this study, an outdoor inquiry program for learning biology using the digital twin focuses on allowing students to freely replicate, organize, and manipulate the real world with simple digital device manipulation. Therefore, we can propose the following implications.

First, anyone can easily create and utilize a virtual world to expand to a variety of learning biology fields. The learning program using the digital twin platform in this study focuses on learners creating dynamic learning content that is more than just 3D space and continuously interacting with the real world. Therefore, it can be used to implement new ways and ideas in learning biology that broadens the boundaries of indoor and outdoor learning. For example, digital twin data acquired continuously at a particular point can monitor changes in plant populations over time. In addition, visualized 3D and multimedia information about ecosystems in different regions can be continuously updated and used for long-distance project learning. Also, various uses such as simulating dangerous experiments, individualized classes for students with different experiments, and saving time through repetition of the same experiment will be possible.

Second, anyone anywhere can use the virtual world just using a mobile device, helping bridge the digital divide. The digital divide in learning using virtual reality is occurring at national, regional, school, and home levels, and without professional equipment and expertise, students could not even create a virtual world. These problems cause differences in opportunities for teachers and students to build and experience a virtual world, and they act as problems that widen the digital divide. However, the virtual space replication activities and educational utilization proposed in this study can be used at the student level without professional knowledge, only on mobile devices with internet access. Therefore, if anyone can choose the target space they want to explore, quickly replicate it in the virtual world, and use it for learning, they can close the digital gap.

Declaration of Interest

The authors declare no competing interest.

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PERCEPTIONS OF PRIMARY PRE-SERVICE TEACHERS IN THE UTILIZATION OF PLANT IDENTIFICATION APPS AS EDUCATIONAL TOOLS

Peter Paul Canuto

Abstract. *Plant identification apps make learning about plants more convenient. This study explored the participants' perceptions of using three plant identification apps, PlantNet, PictureThis, and LeafSnap, as potential educational tools. Problems experienced, differences in perceptions, and the participants' most preferred apps were also determined. Through purposive sampling, the study engaged 162 primary pre-service teachers in the Cordillera Administrative Region (CAR), Philippines. Data were collected through a developed questionnaire and analysed quantitatively. The questionnaire was reliable with an identified single component for perception. Participants first explored and used the apps to identify local plants, thereafter, responding through an online questionnaire. Results showed that participants strongly perceived the apps as engaging, helpful in plant identification, easy to browse, providing details, effective as emerging tools, and significant for scientific literacy, except for consistency of results. There were significant differences, but with small effect sizes, indicating negligible differences in the perceptions of male and female participants regarding the apps' consistency of results and effectiveness. Weak internet connection was the primary issue affecting the apps' utilization. The pre-service teachers preferred LeafSnap over PictureThis and PlantNet. Conclusively, this study affirmed the potential of the apps for students learning about plants, further supporting their feasibility as emerging educational tools.*

Keywords: *educational tools, plant identification apps, PlantNet, PictureThis, LeafSnap, primary pre-service teachers*

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Introduction

Teaching botany among students has always been challenging. However, rapid technological advancement and the integration of computer science research paved the way for the development of mobile learning that supports and promotes plant profiling and raising plant awareness. One such advancement to support learning about plants is automated plant identification apps that can be readily downloaded and installed on smartphones. Utilizing plant identification apps combined with the curation of digital plant images and image recognition technology is already becoming functionally significant (Boho et al., 2020; Jones, 2020) as it easily supports our ability to identify plants (Wäldchen et al., 2018).

Sadly, there has been a drop in the public's knowledge and interest in studying plants, which may result from urbanization and the industrial and technological revolution (Burke et al., 2022). There is also an observed lack and underrated interest in plants among students despite their ecological and economic relevance (Weigelt et al., 2022). Some studies indicated that most students preferred to study animal species compared to plants (Balas & Momsen, 2014; Wandersee & Schussler, 1999). Students also find plant identification more complex and tedious than animal identification (Wang, 2017). These factors may relate to the concept of "plant awareness disparity (PAD)", proposed by Parsley (2020). This concept expounds the individual's tendency to ignore plants in their surroundings, where they visualize plants as a scenic aggregation of green mass secondary to animals (Parsley, 2020; Parsley et al., 2022).

PAD is a modified term of "plant blindness" by Wandersee and Schussler (1999) since the former term is often perceived as associated with visual disability and discriminatory towards persons with disabilities as a whole (McDonough MacKenzie et al., 2019; Parsley, 2020). Students experience PAD depending on their attention or regard for plants, attitude or feeling of learning about plants, knowledge or recognition of the relevance of plants, and relative interest between plants and animals (Parsley, 2020; Parsley et al., 2022). This occurrence may be due to one's perception and how the brain functions (Strgar, 2007). Students perceive that they have more similar characteristics to animals, such as movement and physical resemblance, than

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plants (Hoekstra, 2000). Students strongly (Prokop & Fančovičová, 2023) and automatically prefer animals first to plants since they belong to the animal kingdom (Flannery, 2002).

Plants are vital players in biogeochemical processes, such as carbon and nitrogen cycles, contributing to our approaches related to global climate and climate change. With the importance of plants, schools and teachers should keep their instruction manageable because they are significant to our understanding of ecosystems (Pany et al., 2019) as it underpins food webs (Hill, 2022). Because of these factors, teachers must engage and exert effort to raise interest in botany and promote student plant awareness and appreciation (Pany et al., 2019; Strgar, 2007). One way to achieve these goals is through plant identification applications (apps) that enable the students to gain knowledge of plant species (Zhu et al., 2017).

There has been a significant increase in the use of plant identification apps over the years (Baker, 2023). With the correct plant identification app, individuals can contribute to citizen science initiatives, engage with nature, and determine which plant species are invasive or dangerous (Airhart, 2023). Nonetheless, these apps must be meticulously utilized to effectively impact science literacy and citizen science. It is therefore recommended to use plant identification apps that have reputable sources, such as government or university-affiliated sites (Hill, 2022). It is noteworthy to use apps thoroughly tested and evaluated for their accuracy in identifying plants (Pärtel et al., 2021). In the academe, teachers must use these apps based on reputable sources and expert systems to ensure their contribution to students' plant knowledge (Wang, 2017).

Literature Review

Botany in the Primary Science Curriculum and Local Plants

The present Kindergarten to Grade 12 (K to12) Science Curriculum of the Philippines aims to develop scientifically, technologically, and environmentally literate students. These literacies enable them to become productive in the community, solve complex problems, be innovative, make well-informed decisions, communicate effectively, exhibit scientific attitudes and values, and become responsible custodians of nature. This curriculum employs a spiralling progression of scientific concepts in Chemistry, Biology, Physics, and Earth and Space Science, leading to a deepened understanding of the students as they progress to higher levels. In particular, formal teaching of Science as a discipline starts at the Grade 3 level. From Kindergarten to Grade 2, science learning focuses on exploratory activities and arousing students' curiosity about the natural world to foster basic scientific knowledge and skills development. These conditions invoke students' readiness for formal Science learning (Department of Education, 2016).

The Philippine K to 12 Science Curriculum also underscores localized learning of plants found in the community. It reiterates that students need to learn about their local plants to understand food and nutrition, biodiversity, sustainability, medicinal and traditional uses, and strengthen plants' cultural awareness and heritage (Department of Education, 2016). The Cordilleran region is an agricultural community situated in mountain ranges. Due to its location, temperatures, humidity, and weather patterns differ across the region, making it ideal for various vegetable and fruit crops, including ornamental cut flowers. Some examples of locally grown vegetable and fruit crops include but are not limited to mongo or munggo (mung bean), camote (sweet potato), broccoli, cauliflower, okra (lady's fingers), kangkong (water spinach or swamp cabbage), lettuce, pechay (napa cabbage or snow cabbage), ampalaya (bitter gourd) fruit, tomato, string beans, squash, ginger, bell pepper, carrots, gabi (taro or taro root), radish, potato, camote (sweet potato), and cassava (Philippine Statistics Authority, 2022). Likewise, ornamental cut flowers include gladiola (sword lily), asters, gerbera daisies, coloured and white calla lilies, Shasta daisies, chrysanthemum, agapanthus (Lily of the Nile or African lily), anthuriums, statice (sea lavender), baby's breath, alstroemeria (Peruvian lily), milflores (hydrangea), lisianthus, carnations, and snapdragons (Cabreza, 2023) to name a few.

The foundations of learning about plants are laid at the primary level. Teachers formally introduce the students to the natural world, associating it with their basic scientific knowledge and skills. In this stage, students are exposed to the incredible diversity of plant life on Earth's ecosystems. They will learn to identify different types of plants, their parts, growth patterns, adaptations, modes of reproduction, and habitats. The plants' functions in the environment, their benefits, and proper care are also emphasized. This leads the students to develop recognition and appreciation for the vast array of colours, shapes, and sizes of plants (Department of Education, 2016).

Consequently, having innovative and creative teaching aids and supplementary resources is a must among

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teachers. These resources help the teachers instil a sense of wonder, curiosity, respect for the natural world, scientific literacy, environmental awareness, plant appreciation, and an understanding of the interconnections between plants, humans, and the environment. For these reasons, primary school teachers need a spectrum of educational materials that can be used inside and around the community. Using plant samples, slide presentations, and video clips is practical in teaching botany. Nonetheless, using interactive, digital, and mobile learning will contribute further to students' learning about plants, allowing them to explore more plants in their environment. Hence, the reason for exploring pre-service teachers' perceptions of the potential of plant identification apps as educational tools. As pre-service teachers, they are gaining and developing knowledge and skills for facilitating learning by using a broad range of teaching methodologies, innovative and creative resources, and utilizing educational technologies that they could apply in their future teaching profession (Commission on Higher Education, 2017). Allowing them to explore the plant identification apps and understand their perception may engage the pre-service teachers to effectively employ these apps during their practicum or future teaching endeavours.

Plant Identification Apps

Automated plant identification apps are mobile apps that use photo recognition algorithms and software programmed to identify plants (Pimm et al., 2015; Sachar & Kumar, 2021). Typically, the user takes a photograph of the whole or any of the parts of the unknown plant and then uploads it to the app's system. Once the photographs are uploaded, the app compares them to its database, analyses them, and then provides output or lists of closely possible results (Sachar & Kumar, 2021; Wäldchen & Mäder, 2018). For apps that provide lists of closely possible results, the first plant presented is considered the highest possible identification of the plant. In contrast, the others are suggestions allowing the user to select the most accurate result (Schmidt et al., 2022).

The app's databases may come from various sources, such as crowdsourced observations, remotely sensed images, or specimen collections from museums or herbariums worldwide (Pimm et al., 2015; Sachar & Kumar, 2021). Conveniently, the leaf is the most photographed plant part due to its presence throughout the year (Sachar & Kumar, 2021), regardless of the seasons. Characteristics used for comparisons and analysis between the uploaded photograph and the app's databases include the leaf's colour, shape, texture, and venation (Sachar & Kumar, 2021; Wäldchen & Mäder, 2018). Other plant parts commonly used by these apps for identification include stems, bark, flower, or fruits (Jones, 2020; Rzanny et al., 2019; Schmidt et al., 2022).

The selection of plant identification apps, PlantNet, PictureThis, and LeafSnap, involved in this study was primarily based on Hill's (2022) long-term evaluation. From 2018 to 2021, Hill (2022) and their students tested 14 apps concerning the apps' accuracy in identifying plants. In 2021, they tested eight apps up to 90 to 140 times to identify plants at the W. J. Beal Botanical Garden, Michigan State University. They have photographed plants of flowering broadleaf ornamental species and several kinds of flowering and vegetative weeds categorized by broadleaf weeds, grass or grass-like weeds, and a seedling winter annual weed. Their study also included the botanical garden's usual agricultural and turf weeds. In the end, as of the fall of 2021, Hill (2022) ranked PictureThis as the top-performing app based on the app's comparative percentage of correctly identifying the plants. The PlantNet app ranked second, while LeafSnap ranked fourth. PlantStory, the third in rank, was not chosen for this study since it was newly evaluated by Hill (2022) in 2021, unlike the other three apps. PlantStory is also best described as a marketplace for plants, focusing on commercial rather than educational purposes.

PlantNet

PlantNet or Pl@ntNet is an excellent software for identifying plants quickly. It also provides consistent and accurate identifications of plants compared to others. The app functions through the support of the Agropolis Foundation. It was developed as a project through sponsorship of four French research institutes consisting of the National Institute of Agricultural Research (INRA), the French National Research Institute for Sustainable Development (IRD), the French Institute for Research in Computer Science and Automation (INRIA), and the French Agricultural Research Centre for International Development (CIRAD), including the Tela Botanica Network (Baker, 2023; Wäldchen et al., 2018).

PlantNet provides guides on how to use the app's features (Baker, 2023). Using filters, it can identify plants using photos of leaves, flowers, fruits, or bark. It also uses the Global Positioning System (GPS) and Map option to accurately identify plants (Baker, 2023; Wäldchen et al., 2018). It relies on quality image recognition and user

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involvement (Baker, 2023). It can share photo documentation for research purposes but does not share data with third parties for advertisement (Airhart, 2023). PlantNet also supports multiple languages (Baker, 2023) and does not contain pop-ups and ads requiring users to pay for other features (Airhart, 2023). However, it does not give detailed information, which may be lacking for others (Airhart, 2023).

Based on the evaluations of Hill (2022), PlantNet emerged as the second top-performing app. It achieved 55% accuracy in identifying seedling winter annuals and almost the same performance as PictureThis in identifying vegetative grass-like weeds. Hart et al. (2023) determined the apps' accuracy at 86.6%. On the other hand, based on the works of Hill (2022), CNN journalist Baker (2023) and her colleagues conducted a related evaluation and concluded that PlantNet is the most accurate plant identification app among the apps they have tested. Thus, they highly recommend PlantNet as the best app for most people. Another evaluation of the app by The New York Times Wirecutter journalist Airhart (2023) and her colleagues found that PlantNet is simple, quick, and easy to use compared to other apps, ultimately picking the app as the best among the apps they have also tested. Alternately, Otter et al. (2020) found that the app had 47% accuracy in identifying toxic plants, making it second in rank.

PictureThis

PictureThis is a plant identification app developed by Glority Global Group Limited, an artificial intelligence (AI) resource based in China. It uses AI deep learning technology to search its database and identify plants (Parkins, 2019). Their official website shows that the app can identify more than 10,000 plant species. PictureThis provides topics related to the identified plant, such as full description, toxicity, informative videos, and natural history in considerably more detail (Airhart, 2023). Aside from these, it has a "plantpedia", a digital plant encyclopedia containing helpful information, such as ideal habitat, soil requirements, planting season, and pest control. The app allows users to share pictures and answer plant-related questions through its worldwide social community and forum sections. It also has a "flower map" feature that allows users to tag plants in their locality (Parkins, 2019).

Hill (2022) concluded that PictureThis is the top-performing app. Hill (2022) and her students found that PictureThis ranked the top-performing plant identification app with 67% accuracy among the 130 plant samples. It maintained its number-one rank four years in a row. Further, it was the favourite of Hill's (2022) students due to its high accuracy and ease of usage. Though it maintained its top rank, it presents a low accuracy of 47% when identifying vegetative grass or grass-like weeds compared to other categories. Accordingly, a closer inspection of the grass structures, such as floret and ligule, is necessary and is mostly not seen in the whole plant picture. Similarly, Schmidt et al. (2022) found that PictureThis resulted in a high correct identification of 81.36% genus and 67.84% of species of combined leaf and bark structures among 55 tree species. With these high accuracy results, they will likely recommend the app for their students' use. Another study by Otter et al. (2020) concluded that the app was the best among the apps they have used, with a 59% accuracy rate in identifying toxic plant species. On the contrary, Airhart (2023) and her colleagues found that PictureThis is less user-friendly than the other tested apps. It is also too easy to unintentionally subscribe to paid extra features and advertisements popping up from the app.

LeafSnap

LeafSnap was developed by researchers from the Smithsonian Institution, the University of Maryland, and Columbia University (Wäldchen et al., 2018). It compares the plant's picture to its database of over 9000 images (Kress et al., 2018). The app retrieves photos on its database similar to the uploaded one. However, the user has the last say in whatever species they think best fits the findings (Wäldchen et al., 2018). LeafSnap has a broader, more accurate advanced identification function that can identify the plant using photos of the whole plant, leaves, or flowers. It presents caring guides and reminders for plants which can be helpful for the users. Users can also create plant photo collections and data sharing (Baker, 2023). Moreover, it provides background information about the species and its geographic location (Kress et al., 2018).

Compared with other apps, LeafSnap was identified as the fourth-best app by Hill (2022). It achieved an accuracy of more than 40%. It was able to have better performance in identifying flowering ornamentals. Wäldchen et al. (2018) indicated that LeafSnap achieved 96.8% among 184 tree species, making it to the top five and an overall recognition rate of 73% accuracy. Hart et al. (2023) measured the apps' accuracy at 86.9%. Alternatively,

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Kress et al. (2018) observed a 10% to 100% accuracy variance among the tree species samples. Nonetheless, they have noted that LeafSnap is continuously undergoing improvement using deep learning. Moreover, Airhart (2023) observed that using the app presented challenges since operating could be more intuitive. It also presents pop-ups and advertisements that may cause accidental subscription of the user.

Research Gap to be Filled

Even with the growing number and use of plant identification apps, only a few studies (Wang, 2017; Yujuan et al., 2021) were conducted on the feasibility and capability of mobile plant identification apps as educational tools. Most studies conducted on these apps focused primarily on their features, accuracy, user-friendliness, and downsides (Airhart, 2023; Baker, 2023; Hart et al., 2023; Hill, 2022; Kress et al., 2018; Otter et al., 2020; Pärtel et al., 2021; Schmidt et al., 2022; Wäldchen et al., 2018). There is still a lack of recognition of these apps' potential for science teaching. This prompted the researcher to explore the prospect of using plant identification apps for learning about plants which are deemed beneficial to raise plant awareness and recognition and impede PAD among the students. Instead of accuracy, this study centred on examining and understanding the perspective of future primary school teachers about their views and experiences, thereby acknowledging the capabilities of the apps to be used in science education.

Research Aim and Research Questions

This study aimed to explore the potential of three plant identification apps, PlantNet, PictureThis, and LeafSnap, as emerging and interactive educational tools for students learning about plants. Mainly, it aimed to determine the perceptions of primary pre-service teachers in using the apps as a probable teaching aid in upper primary grade levels and their significance for supporting the development of scientific literacy. It also aimed to determine the problems experienced by the participants in using the apps. The differences between the participants' perceptions according to gender and their most preferred app were also determined. Moreover, the following research questions guided the conduct of this study:

1. What are the primary pre-service teachers' perceptions regarding using plant identification apps as educational tools?
2. Are there significant differences among the participants' perceptions according to gender?
3. What are the problems experienced by the participants while utilizing the apps?
4. Which app is the most preferred one by the participants?

Research Methodology

Research Design

The researcher employed a quantitative approach to gather and analyse the perceptions in using the three plant identification apps for learning about plants and the challenges experienced by the participants. A descriptive survey was used to understand the characteristics of the participants (Anastas, 2000), leading to the exploration of the participants' insights and struggles concerning the apps. Meanwhile, inferential statistics was used to compare the differences (Kuhar, 2010) among the participants' perceptions of utilizing the apps for teaching about local plants. This exploratory study focused on primary pre-service teachers' perceptive views and ordeals regarding their future use of plant identification apps. The pre-service teachers were enrolled in Bachelor of Elementary Education (BEEd) from four state and private universities in the Cordillera Administrative Region (CAR), Philippines. The BEEd leads explicitly to a teaching profession at the primary level. The apps utilized by the participants involved three plant identification apps that were selected based on the long-term study of Hill (2022). The participants used the apps to identify locally grown vegetable and fruit crops and ornamental plants around their community. The participants' overall perceptions and differences according to gender, problems they encountered, and most preferred apps were determined using an online survey questionnaire provided through email. The study was conducted throughout the two semesters of the academic year 2021 – 2022.

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Participants

The study involved 162 BEEd pre-service teachers. They comprised second to fourth-year undergraduate students, involving 46 (28%) males and 116 (72%) females. The number of participants was based on those pre-service teachers who volunteered, consented to this study, fully utilized the plant identification apps, and thoroughly answered the online questionnaire. Preliminary to data gathering, request letters were sent to a total population of 176 primary pre-service teachers enrolled in four universities. However, only 162 out of 176, or 92% of the participants, fully agreed, had used the apps and entirely responded to the questions. The remaining 8% of the participants either withdrew their participation or submitted incomplete responses. A 92% of positive responses resulted most likely due to the follow-up reminders (Fincham, 2008; Menon & Muraleedharan, 2020) undertaken by the researcher, attaining enough data to represent the population.

Furthermore, the participants were determined through purposive sampling, enabling their selection based on the structure of this study (Creswell et al., 2011). The curriculum design, objectives, and career opportunities of the degree, which calls for the development of qualified teachers with specializations in content and pedagogy for primary education (Commission on Higher Education, 2017), guided the selection of the BEEd pre-service teachers. The participants' gender is the only variable considered in the study. The year level of the participants was not included since some were classified as irregular students. In the context of the country's universities, an irregular student is a student who is enrolled with less than the prescribed number of course subjects or units in a given semester required by the curriculum of the degree program. It may also pertain to students attending classes across different year levels of the same program to comply with the required number of units for the degree. For the irregular students involved as participants, it is difficult to determine their specific year level; hence, the year level is excluded.

Instrument

The researcher primarily developed the questionnaire with four sections. The first section of the questionnaire gathered the profiles, indicating gender, year level, and classification as either regular or irregular students, from the primary pre-service teachers. The second section comprised seven question items, as presented in Tables 4 and 5, items 1 – 7, regarding the participants' perceptions of the apps. These question items will be rated through a 5-point Likert scale measured with 1 = Strongly Disagree (SD), 2 = Disagree (D), 3 = Neutral (N), 4 = Agree (A), and 5 = Strongly Agree (SA). The third section consisted of a checklist with five question items enumerated in Table 6, items 1 – 5, regarding the problems they encountered while using the apps. This section allowed the participants to select the given options more than once. A selection of the three apps presented in Table 7 is the last section of the questionnaire prompting a singular response from the participants to choose the best app to use in teaching significant lessons related to local plants. The question items were integrated into an online questionnaire created using Google Forms.

Reliability and Factor Analysis

Content validation of the questionnaire was first requested from three faculty members with expertise in Biology teaching. Some of the statements were then paraphrased based on validations. Thereupon, pilot testing was conducted involving 30 primary pre-service teachers from a state and a private university in the same region, excluding these universities during the primary data gathering. As a result, the questionnaire was found reliable, with a determined coefficient of reliability of .952 using Cronbach's alpha. Subsequently, exploratory factor analysis was done on the seven question items regarding perception, ruling out questions concerning problems with multiple responses and the most preferred app. The correlation matrix in Table 1 shows that the Pearson correlation coefficient of each question item ranges from .409 to 1. Most items showed a high correlation with each other, considering a correlation coefficient of .60 and above, indicating that the items belonged to the same factor. Those items with a correlation coefficient of below .60 showed moderate correlation, such as in the case of Item 3 correlated with Items 4, 5, 6, and 7. There were no negative and weak correlations identified among the items.

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Table 1
Correlation Matrix of Question Items Regarding Perceptions

		Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
Correlation	Item 1	1.000					
	Item 2	.631	1.000				
	Item 3	.608	.544	1.000			
	Item 4	.510	.653	.581	1.000		
	Item 5	.681	.709	.409	.454	1.000	
	Item 6	.576	.769	.445	.466	.727	1.000
	Item 7	.538	.775	.487	.634	.703	.806

Kaiser-Mayer-Olkin (KMO) and Bartlett's test of sphericity was also done. The KMO was determined as .859 (greater than .70), indicating enough items to produce a factor. Likewise, Bartlett's test is significant ($\chi^2(21) = 133.65$, $p = .001$) at 5%, showing that the variables were correlated highly enough to provide a reasonable basis for factor analysis. Based on the total variance explained shown in Table 2, only the first component has an eigenvalue greater than 1. This result stipulated that there is only one possible factor. The cumulative percent showed that only one factor accounts for 66.54% of the variance.

Table 2
Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.658	66.539	66.539	4.658	66.539	66.539
2	.806	11.521	78.060			
3	.582	8.315	86.375			
4	.370	5.292	91.667			
5	.228	3.258	94.924			
6	.207	2.964	97.889			
7	.148	2.111	100.000			

Similarly, the component matrix shows that only one factor was extracted, as indicated in Table 3. Item 2 has the highest correlation value among all the items, indicating its strong association with the only component. Meanwhile, Item 3 has the lowest correlation value, though still indicating a strong association with the component. The remaining items also disclosed strong associations based on their correlation values. Since there is only one component, all items were correlated with only one factor. Considering all the question items, the commonality among them is that they all relate to using and evaluating the mobile apps used for plant identification, referencing the user's perceptions.

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Table 3
Component Matrix of the Items

Items	Component
	1
Item 2: I found the mobile apps helpful for identifying plants	.899
Item 7: The mobile apps are significant for supporting scientific literacy	.876
Item 6: I found the mobile apps as an effective emerging tool for learning about plants	.852
Item 5: The mobile apps provide significant details about the plants	.830
Item 1: I found the mobile apps engaging for plant exploration	.792
Item 4: There is consistency of results among the three mobile apps	.745
Item 3: I found it easy to browse within the mobile apps' interface	.697

Procedures

First, a letter of permission indicating the study's objectives and the participants' contribution was sent to the target primary pre-service teachers through emails. Then, consent forms asking for the participant's involvement in the study were also sent to those who positively gave their permission. After the participants' approval, they were instructed to download and install the three plant identification apps, PlantNet, PictureThis, and LeafSnap, from either Play Store for Android systems or App Store for iOS systems, depending on the model and compatibility of their smartphones. Afterwards, the participants were asked to use the plant identification apps to identify local vegetable and fruit crops and ornamental plants they liked. The plants to be identified may or may not be familiar to them. They may take photos of the whole plant, its flowers, leaves, of barks. The participants were allowed to use the apps to identify unlimited local plants. This condition allowed the participants to be immersed in using the apps and familiarize themselves with their features. However, they were only allowed to finally choose five plants for the purpose of this study. They also had to take note of the scientific name of the identified plant by the apps for comparison of result consistency. For monitoring and record purposes, the participants were also instructed to take a screenshot of the apps' results and send it through the researcher's email. After using the apps, a link to the Google Form containing the online questionnaire was forwarded to the participants for them to answer. Results were then tabulated using spreadsheets. The conduct of this study upholds the practice of scientific inquiry and the ethical and professional standards in doing research. The contact information, especially the participants' email addresses, was gathered through their professors' referrals and was strictly used for communication purposes relevant to this study. Consent forms were asked from the participants' emphasizing their voluntary participation. The online questionnaire was sent and monitored personally by the researcher. The submitted responses and their tabulated data were compiled and kept confidential.

Data Analysis

A statistical limit of weighted mean was used to analyse the perception of the utilization of the plant identification apps for learning about plants among the participants. The statistical ranges consist of 1.00 – 1.80 = Strongly Disagree (SD), 1.81 – 2.60 = Disagree (D), 2.61 – 3.40 = Neutral (N), 3.41 – 4.20 = Agree (A), and 4.21 – 5.00 = Strongly Agree (SA). Frequency count, percentage, and ranking were used to determine the problems experienced by the participants in using the apps and to determine their most preferred teaching tool among the three apps. Moreover, a t-test was used to test if there were significant differences in the level of perceptions of the use of the apps between the male and female primary pre-service teachers.

Research Results

Table 4 shows that the primary pre-service teachers have strong perceptions towards the three apps after using them, except for one item. They strongly agree that the apps were effective emerging tools for learning about plants, followed by helpful apps for identifying plants. The participants expressed the same level of agree-

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ment regarding the apps' features in providing significant plant details and engaging for plant exploration. There is also a strong agreement relating to the apps' ease of browsing and significance for supporting scientific literacy. Notably, they have a lower level of agreement on the apps' consistency of results.

Table 4
Perceptions of the Primary Pre-service Teachers in Using the Plant Identification Apps as Probable Educational Tools

Perceptions	*M*	*SD*	Level
1. I found the mobile apps engaging for plant exploration	4.43	0.802	Strongly Agree
2. I found the mobile apps helpful for identifying plants	4.46	0.723	Strongly Agree
3. I found it easy to browse within the mobile apps' interface	4.35	0.784	Strongly Agree
4. There is consistency of results among the three mobile apps	3.91	0.866	Agree
5. The mobile apps provide significant details about the plants	4.43	0.738	Strongly Agree
6. I found the mobile apps as an effective emerging tool for learning about plants	4.49	0.766	Strongly Agree
7. The mobile apps are significant for supporting scientific literacy	4.31	0.774	Strongly Agree

There are variances in the participants' perceptions when grouped according to their gender, as Table 5 indicates. Though there is an overall strong agreement concerning the three plant identification apps, there are peculiar differences between the participant's perceptions at the .05 critical level. There are no observed significant differences in most perceptions between male and female pre-service teachers. On the other hand, results indicate significant differences between the male and female participants' perceptions towards the apps' consistency of plant identification results (p = .020) and effectiveness as emerging tools for plant learning (p = .043). However, further analysis (not shown in the table) conveyed that the effect size, determined by Cohen's, was d = 0.49, indicating a small effect size between the participants' perceptions of the apps' consistency of plant identification results. Similarly, the measured Cohen's was d = 0.47, indicating a small effect size regarding the effectiveness of the apps as emerging tools for plant learning. Thus, the effect sizes between the male and female participants concerning the two perceptions are negligible, even if they are statistically significant.

Table 5
Differences in the Participant's Perceptions in Using the Plant Identification Apps as Probable Educational Tools According to Gender

Perceptions	Males		Females		*df*	*t*	*p*
	M	*SD*	*M*	*SD*			
1. I found the mobile apps engaging for plant exploration	4.46	0.520	4.41	0.697	95	.325ns	.746
2. I found the mobile apps helpful for identifying plants	4.35	0.587	4.50	0.496	77	-1.166ns	.247
3. I found it easy to browse within the mobile apps' interface	4.37	0.594	4.34	0.628	85	.183ns	.855
4. There is consistency of results among the three mobile apps	3.65	0.810	4.02	0.695	77	-2.377*	.020
5. The mobile apps provide significant details about the plants	4.30	0.572	4.47	0.530	80	-1.302ns	.197
6. I found the mobile apps as an effective emerging tool for learning about plants	4.28	0.741	4.58	0.507	71	-2.062*	.043
7. The mobile apps are significant for supporting scientific literacy	4.17	0.680	4.36	0.563	76	-1.342ns	.183

Note: * = significant (p < .05); ns = not significant (p > .05)

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Aside from perceptions, Table 6 presents the problems encountered by the participants in using the three apps. Overall, the main problem encountered by the primary pre-service teachers relates to a weak internet connection that affected the apps' functions. This is followed by the consistency of results, the need for a subscription, the compatibility of the apps with their smartphones, and the complexity of the apps' interface. Further analysis showed that three problems attained the same ranking from both genders except the remaining two. Male and female pre-service teachers experienced the same problems concerning poor internet connectivity, the consistency of plant identification results of the three apps, and the need to fully subscribe to use the apps' features. Males, however, experience more complications in using than the compatibility of the apps. Females struggled more with the compatibility with their smartphones than the difficulty of the apps' user interface.

Table 6
Problems Experienced by the Participants in Using the Plant Identification Apps

Problems experienced	Male			Female			Overall		
	f	*%*	Rank	*f*	*%*	Rank	*f*	*%*	Rank
1. The plant identification results are not consistent among the three mobile apps	13	19	2	34	21	2	47	21	2
2. The mobile apps are not compatible with the smartphone's specifications	9	13	5	15	9	4	24	11	4
3. The mobile apps' interfaces are complex to utilize	10	15	4	12	8	5	22	10	5
4. Subscription is needed among the mobile apps	12	18	3	26	16	3	38	16	3
5. The mobile app functions are affected by a weak internet connection	24	35	1	73	46	1	97	42	1

Regarding preferences shown in Table 7, LeafSnap emerged as the primary pre-service teachers' most preferred plant identification app. The other apps, PictureThis and PlantNet, ranked second and third, respectively. Correspondingly, the top preferred app between males and females varies. Males highly preferred PictureThis compared to LeafSnap by the females. Males secondarily chose LeafSnap, while females selected PictureThis. Both genders identified PlantNet as their least preferred among the three apps.

Table 7
The Most Preferred Plant Identification App Among the Participants

Plant identification apps	Male			Female			Overall		
	f	*%*	Rank	*f*	*%*	Rank	*f*	*%*	Rank
PlantNet	10	22	3	26	22	3	36	22	3
PictureThis	22	48	1	37	32	2	59	37	2
LeafSnap	14	30	2	53	46	1	67	41	1

Discussion

The overall perception regarding the plant identification apps of the primary pre-service teachers showed strong agreement, indicating the apps' prospective use as educational tools. This highlights the emerging and effective use of mobile learning through smartphones. The importance of teaching students about plants as fundamental to Biology (Pany et al., 2019; Strgar, 2007) may further increase due to using these apps. Aside from citizen science and scientific literacy, the students' technological literacy will be advanced. The fact that the participants find the apps engaging for exploring and helpful in identifying local plants reinforces the recognition and awareness of plants in our surroundings. These apps aid active and interactive learning outside of the classroom. Wang (2017) deduced that these apps contribute to students' outdoor engagement, affecting their learning and behaviour.

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The participants' strong agreement on the ease of using and browsing the apps agrees with Airhart's (2023) general observations of some apps. Most apps are user-friendly and contain menus and tabs that are easy to navigate. These features cause hassle-free browsing by the users. The essential details the apps provide about the identified plants are beneficial. As Airhart (2023) indicated, this feature gives users relevant information about the plant. This may enable the users to acquire knowledge and further explore the plant's growth and development, structure, habitat, and palatability. The details can then contribute to understanding the plant's aesthetic and biological features, as Wandersee and Schussler (1999) pointed out.

The strong perception of both primary and pre-service teachers on the potential of the apps to be used as an effective emerging tool for learning about plants and their significance in supporting scientific literacy affirms the usefulness of plant identification apps in education. This study supports and further contributes to the works of Wang (2017), implying the feasibility of plant identification apps in science instruction. It also supports Yujuan et al. (2021), who recommend using plant identification apps to train autonomous learning of students about plants. Wang (2017) concluded that these apps significantly improved the students' science learning and attitudes and caused better learning satisfaction than traditional teaching methods. With these apps, students may be able to identify plants easily (Wäldchen et al., 2018), nurture plant knowledge (Zhu et al., 2017), and to further recognize and appreciate plant's role in the biosphere (Hill, 2022; Pany et al., 2019). This may then lead to an increase in students' plant awareness and reduce their PAD. However, it must be noted that teachers must choose apps that are extensively evaluated (Airhart, 2023; Baker, 2023; Hill, 2022; Kress et al., 2018; Otter et al., 2020; Schmidt et al., 2022; Wäldchen et al., 2018) and uses reputable sources and expert systems (Hill, 2022; Pärtel et al., 2021) to ensure positive students' learning.

Regarding the consistency of results of the three apps to which the participants considerably agreed, it confirms the findings and evaluations of identified studies (Airhart, 2023; Hart et al., 2023; Hill, 2022; Kress et al., 2018; Otter et al., 2020; Schmidt et al., 2022; Wäldchen et al., 2018) that not all three apps provide the same plant names. The variances in the results imply the limitations of the apps and their accuracy in identifying plants through images. Despite the advancement of automated learning, AI, and deep learning, circumstances affecting the apps' accuracy rate are still unclear (Hart et al., 2023).

Though there are observed significant differences in the perceptions of the male and female pre-service teachers towards the apps' consistency of results and effectiveness as emerging tools for plant learning, their measured effect sizes are small. This implies trivial differences between the male and female perceptions, having low effect sizes and negligible differences. In this case, there are no practical variances in all of the pre-service teachers' perceptions according to gender. There are no differences in how the male and female participants perceive the apps' engaging capability for plant exploration, helpfulness in plant identification, ease of browsing, consistency of results, providing details, effectiveness as potential educational material, and relevant support for scientific literacy.

A weak or poor internet connection is the participants' main problem in using the apps. This condition is primarily affected by the country's performance in providing internet services, the cost of internet services and subscriptions (Rosales, 2023; Samaniego, 2023), telecommunications infrastructure, and the geographical environment (Salac & Kim, 2016). Due to poor connection, the participants may have difficulties accessing the features of the apps, uploading images, and loading results. Since these apps use online databases, a strong internet connection is advisable.

Problems relating to the consistency of results among the apps were also experienced. Accordingly, the consistency and accuracy in the plant identification results may be affected by several factors, including the diversity and differences of leaves as the basis for identification (Sachar & Kumar, 2021; Zhang et al., 2020), the bias and validation between the tests and the sample plant images which may result to unreliable species labels (Jones, 2020; Rzanny et al., 2019), the short span of production of flowers and fruits among plants (Perera & Arudchelvam, 2021), the lack of data presentation and depiction of other organs of the plant (Boho et al., 2020), the quality of the images uploaded (Hill, 2022), and the rareness of some species (Jones, 2020). This is especially true in the region since most data stored in the apps' databases are collected from Western countries, affecting the identification of local plants.

Similar to Airhart's (2023) evaluation, subscribing to the apps and the sudden pop-up ads were encountered as well by the participants. In the free versions, some apps provided a minimum number of photos to be uploaded within the day and prevented some features from being accessed, limiting the use of apps. Users must purchase and subscribe to the apps to fully enjoy their system. The participants' struggles with the applications' compatibility with their smartphones and the complexity of the apps' user interfaces are technological and reliant on the apps' software and operating system. Updating the apps, the incorporation of AI (Joly et al., 2016) and deep learning

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(Kress et al., 2018), developers' coding techniques and algorithms (Wäldchen et al., 2018), scientific institutions' contributions and validations (Joly et al., 2016), and image processing (Yanikoglu et al., 2014) may be some of the factors that affected the said problems.

Overall, the pre-service teachers prefer LeafSnap the best over the other two apps despite ranking as the fourth-best app, as Hill (2022) established. However, Wäldchen et al. (2018) still pointed out that the app had high accuracy. They may have ranked LeafSnap as the best due to its ability to provide plant care reminders and create albums of plant collections, as Baker (2023) presented. The second most preferred app is PictureThis, in contrast to Hill's (2022) and Otter's et al. (2020) inferences and Schmidt's et al. (2022) high recommendation of the app for students' use. Though Airhart (2023) found the app less user-friendly and full of pop-up advertisements, the pre-service teachers may have ranked it second due to its features, such as a plant encyclopaedia and local plant tagging, as Parkins (2019) described. PlantNet, the participants' least preferred app, counters the apps' second-best ranks by Hill (2022) and Otter et al. (2020). It does not also contend with Baker's (2023) and Airhart's (2023) high regard for the app. This may be due to the lack of plant information provided by the app, as reported by Airhart (2023), affecting the participants' view of the app. Nevertheless, it is important to note that the participants' preferences do not depend solely on the three apps' accuracy and consistency of results. Instead, it generally involves the participants' perceptions of the apps' features and potential as educational tools, including their experiences using the three apps.

Conclusions and Implications

Utilizing plant identification apps is feasible for classroom learning, as affirmed by the results of this study. The pre-service teachers strongly agreed on the apps' engaging characteristics, usefulness in plant identification, ease of browsing, providing information, effectiveness for learning about plants, and relevance in supporting scientific literacy. The participants showed lower perceptions regarding the apps' consistency of results. It was also determined that there were no significant and practical differences between the male and female participants' perceptions of the apps. This is despite the drawbacks they have experienced while using the apps, mainly affected by weak internet connection. Ultimately, the pre-service teachers selected LeafSnap as their preferred app over PictureThis and PlantNet. Conclusively, these plant identification apps can provide opportunities to reinforce and support instruction. Almost all students nowadays have smartphones and can access the internet. Various plant identification apps are free and readily available to identify plants quickly. Integrating these apps into teaching can be advantageous from an educational aspect and is very important for learning about plants. The use of these apps is recommended and timely, concerning the advancement of technology, its impact on science education, and in strengthening plant awareness for the conservation of natural resources. However, the apps should undergo a thorough and methodical evaluation to ensure their suitability for students' learning and congruence with the objectives of the lessons.

The findings of this study contributed to the enrichment of relevant literature. It also offered a glimpse into the participants' perceptions about the potential of plant identification apps for mobile learning. It allowed the exploration of these apps as emerging educational tools, therefore, presenting the participants' confirmation of the apps' possible classroom use for those educators who may be planning to do so. The non-comparison between the apps' accuracy of results is a limiting factor in the study. Listing the results and analysing their precision and consistency was not employed. Another factor relates to the number of apps involved in the study. There were only three apps explored in comparison to the earlier evaluations. Also, the participants involved were associated with primary grades where learning about plants is considerably at the beginning stage. Lastly, the study focused on the pre-service teachers' perceptions and did not consider student involvement. With these, future researchers should explore the effectiveness of plant identification apps in student learning other than perception. Adding similar and relevant apps is also suggested. Furthermore, an extensive study should be conducted on the apps' practicality as a teaching aid and their impact on science education.

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CORRELATION BETWEEN ENERGY METAPHOR AND EMPATHY TENDENCY

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Abstract. *Creating a metaphor for the concept of energy can contribute to the determination of the mental structuring of the concept of energy. Pre-service teachers' metaphors about the concept of energy were classified according to traditional and scientific fields. The metaphors produced by the mathematics and science teacher candidates for the concept of energy consisted of structural and abstract concepts, approximately 60% of them were the continuity of life and 40% were science categories. While pre-service mathematics teachers mainly produce metaphors for biology, pre-service science teachers produce metaphors mainly for physics. Empathic tendency scores and levels of pre-service teachers were determined. Pre-service teachers have a high level of empathic disposition and predominantly see the other person's problem and emotion as their own. There was no quantitatively significant difference between traditional metaphor types and empathic tendencies. It is understood that the pre-service teachers have high empathic tendencies, and mostly in the you stage, the concepts related to the continuity of life are primarily used in developing metaphors related to the concept of energy, and they tend to produce structural metaphors. Metaphor and empathy will contribute to the determination of mental models and the establishment of a connection between the fields of science.*

Keywords: *energy metaphor creation, empathic disposition and relationship identification*

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Introduction

The cognitive learning theory regards learning as a cognitive process and focuses on mental operations (encoding, storing, and retrieving information) to make sense of the occurrences in the environment. In parallel with the cognitive learning approach, the dominant view of the concept of the metaphor (the metaphor is the art of speaking, embellishing speech, and eloquence) has gradually begun to change. In addition to the art of eloquence, the view that the metaphor is the product of a mental process and that the focus of the metaphor is not a language but a mental mechanism has gained prominence. Lakoff (1993) emphasized that the metaphor is not only the art of eloquence but also reflective of the way of thinking.

While authors, poets, and artists were interested in metaphors and empathy in classical times, today, different fields of science have shown interest in the concepts. Artists reflect the mental models they developed based on their empathic perceptions of their works. Artworks are a product of the artist's emotional, cognitive, and empathic state. Authors and artists have tried to put themselves in the shoes of what they are trying to depict, believing that empathetic understanding is the key to good writing and practical art (Smith, 2012). The person looking at a work of art internalizes the artist's thoughts and feelings through empathy. As how internalization is made varies by person, a work of art evokes different feelings and thoughts in everyone. Metaphors and empathy are a way of reflecting on one's mental models of the world. Metaphors and empathy are similar concepts, and in situations of creating the metaphor and empathy, relationships and similarity patterns are used (Swan & Riley, 2012).

Individuals utilize different features and connections when creating metaphors, which makes metaphors unique to the individual. Empathy, on the other hand, is about how the other person is perceived and internalizing his behavior cognitively or emotionally. Empathy is understanding the other person's feelings, perspectives, or situations and experiencing the other person's emotional state (Swan & Riley, 2012). When a person uses the metaphor and practices empathy, they acknowledge another person's mental models, knowledge, and experiences through mental processes. The metaphor is a way of reflecting perceptions, concepts, and thoughts through mental

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processes. Morgan (1998) defined metaphors as a way of thinking and seeing in perceiving the world. Empathy, on the other hand, is trying to understand the thoughts and feelings of another person and seeing the world from their point of view. Empathy is the ability to make inferences by decoding another person's thoughts, feelings, and behaviors (Swan & Riley, 2012). Metaphors and empathy are mental processes at the end of which the external projection of internalized situations is presented. The metaphor is a way of reflecting perceptions, concepts, and thoughts through mental processes, while empathy is acknowledging the feelings and thoughts of another person. In creating metaphors, mental models are developed based on existing information while empathy is the practice of perceiving the feelings and thoughts of another person and acknowledging them through unique mental models.

The Metaphor

Mental models (scientific models) are defined as a set of meaningful metaphors, and one way of projecting mental models is by using metaphors. Lakoff and Johnson (1980) stated that metaphorical concepts are the essence of scientific thinking and that without them, little can be understood beyond our direct physical experience. Mental models help us understand the surrounding phenomena around us by making meaningful connections with and extending our prior knowledge. Thinking metaphorically enables a new phenomenon to be understood by relating it to previous experiences (mental models). Conceptual metaphors represent the relationship mental models and are created by connections such as relationships and analogies. Additionally, metaphors serve as the interface between mental models and are an element of the mental mapping mechanism, which shapes thinking (Beasley & Waugh, 1996).

It is difficult to directly observe and measure an abstract concept. The concept of energy is appropriately defined within the confines of science, but these definitions do not apply to all fields. For example, students think that the definition of energy in biology is different from that in physics. Lakoff and Johnson's (1980, 1999) conceptual metaphor theory presents an ideal method through which to teach this topic (Amin, 2009; Dreyfus et al., 2014; Lancor, 2014; Scherr et al., 2012). Conceptual metaphor theory plays an important role in understanding abstract concepts, being a cognitive theory arguing for the largely metaphorical nature of the way we understand the world and that most conceptual structures are built based on metaphors that help us make sense of the world through the familiar (Lakoff & Johnson, 1980, 1999). A new experience or concept is constructed by establishing relations between mental models, and metaphors are used in understanding a concept or field based on other concepts or experiences. Metaphorical language is essential for expressing and understanding abstract ideas, and conceptual metaphor theory provides a way for researchers to gain insight into how students understand abstract concepts such as energy (Lancor, 2015). With the metaphor, a new concept, phenomenon, or object is instinctively associated with the important features of the concepts, phenomena, and objects that exist in our minds, making the new concepts, phenomena, and objects understandable. This helps to interact with and make sense of the environment.

When we conceptualize an experience or an idea, we make sense of the experience or idea by picking its most important parts and comparing them with what already exists in the mind. This mental process creates metaphors by pairing phenomena, objects, and concepts otherwise difficult to understand with other concepts that have common characteristics, thus facilitating learning and recall by making them understandable. Metaphorization is explaining a concept or phenomenon by drawing an analogy with another concept and phenomenon (Oxford et al., 1998). The metaphor enables complex and abstract aspects of reality to be understood in more concrete, familiar, and easily imaginable terms (Refaie, 2001; Semino, 2008). Metaphors also contribute to eloquence, are effective in persuading and influencing others, and facilitate strengthening communication and building intimacy between the speaker and the listener (Semino, 2008).

Empathy

The Turkish Language Association (2018) defined empathy as the ability of an individual to put themselves in the shoes of another individual in terms of emotion and thought. Empathy is a human trait, a psychological mechanism, that enables individuals to establish and maintain social relationships and to take an evaluative stance toward the vantage point of aesthetics and epistemology. It is also a behavior that enables individuals to make logical inferences from moral and social mistakes by empathizing and reasoning with and drawing lessons from them. Earlier, empathy was addressed from the vantage point of aesthetics and epistemology. Aesthetic empathy refers to individuals' spontaneous projection of feelings and thoughts while observing objects, whereas epistemological

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empathy has been used by artists and poets as a means to achieve their goals (Gulseren, 2001).

Today, empathy is defined as putting oneself in the other person's shoes, seeing the similarities and differences in the other person's ideas, and respecting and tolerating differences. Respecting others' opinions is important for establishing healthy communication and relationships. Denis (1999) stated that those who are good at building positive relationships generally empathize with people more easily. Empathy is taking the place of the other person and possessing and internalizing the same emotions and ideas as them. Baron-Cohen (2003) defined empathy as the urge to identify the thoughts and emotions of another person and respond to them with an appropriate emotion. Reacting by understanding the other person facilitates healthy social relations and achieving common goals.

The literature distinguishes between two types of empathy, namely cognitive and emotional (Brems, 1989; Hoffman, 1977; Rogers, 1980; Shantz, 1975; Strayer, 1987), and the type of empathy practiced changes by a situation (Gladstein, 1983). Cognitive empathy is the ability to accurately perceive or imagine what another person is thinking and feeling by ascribing mental states to them. This mental process is sometimes referred to as the theory of mind or perspective (Davis, 1983; Hogan, 1969). Emotional empathy is the emotional response of individuals who put themselves in another's place. It refers to sharing emotional responses, for example, feeling distressed in response to the other person's pain or feeling happy in response to their joy. Hoffman (2008) defined emotional empathy as the ability to identify with the emotions of others and to understand what the other individual is feeling. Emotional and cognitive empathy are equally important in communicating with others, perceiving what they are thinking and feeling, relating to them emotionally, and allowing them to share their thoughts. There is a consensus in the literature that these two elements are inseparable (Feshbach, 1975; Greenberg et al., 1993; Greenson, 1960; Katz, 1963; Schafer, 1959; Strayer, 1987).

Metaphors, Empathy and Teaching Energy

In everyday life, mental models are unwittingly used to understand the environment and describe phenomena. Metaphors and empathy are abstract concepts involving mental modeling. Mental models (scientific models) include analogies or metaphors (Aubusson et al., 2006) and are often constructed through analogical reasoning (Collins & Gentner, 1987). Often mental models are verbalized through metaphoric and empathetic responses. These responses serve to activate, elaborate, or modify mental models as in understanding something (Hestenes, 2006). Therefore, understanding the language used to communicate the mental model provides insight into this model (Lancor, 2015). In teaching, with the help of metaphors and empathy, students' mental models of the subjects can be identified, in light of which the course content can be restructured and processes suitable for these mental models can be developed.

Metaphors constantly change due to the physical and cultural interaction with the environment, which enables the development of mental models and paves the way to establishing new connections with different fields. Metaphors can be used as learning outcomes that aim to identify students' mental models and thoughts on the subject. Since metaphors and empathy are projections of mental models, they can be used to restructure the curriculum and teaching methods used and determine learning outcomes. In addition, examples of empathetic utterances can be used in the in-class interactions between students and teachers.

Students can use metaphors as a tool to describe and understand their environment and practice empathy to build healthy communication and relationships. While creating a metaphor, it is possible to expand an existing model or create a new one by establishing relationships, similarities, and commonalities between mental models. They stated that there is a relationship between mental models and metaphors (Duit, 1991; Hestenes, 2006), and empathy is the basis for how we understand someone else's mind and how we reflect our own mental states or create a mental model (Fonagy et al, 1991). Empathy is basically metaphorical (Swan & Riley, 2012), empathy and metaphor are formed as a result of models using mental information, emotions, thoughts and experiences. Metaphors function as a pathway to empathy (Smith, 2012). Familiar terms are used when generating metaphors and practicing empathy. Individuals likely empathize with victims similar to themselves (family members), which is called "familiarity bias" (Hoffman, 2000).

Empathy and metaphors can be utilized in the interactions between students and teachers in the classroom environment. The teacher can empathize with what the students are thinking and feeling with the help of emotional and cognitive expressions such as worry, feedback, understanding, and reaction. This use of empathy makes it easier for the teacher to meet the students' needs. Additionally, teaching-learning models can be adjusted in light of the information about the mental processes and structures students utilize to create metaphors and practice empathy.

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To eliminate the complexity of the concept of energy and establish stronger scientific relationships between the fields, a common definition of the concept of energy is required. In crafting this definition, the relationships between mental models related to the concept of energy can be determined with the help of metaphors. Empathetic tendencies can also help determine the relationships between models and define metaphors. Future metaphor studies can investigate mental models related to the concept of energy within the context of preliminary scientific information. It is necessary to identify students' preliminary information regarding how and why a phenomenon takes place and reorganize the teaching-learning models for the science class in a way to address students' misconceptions (Dekkers & Thijs, 1998; Osborne & Wittrock, 1983). Students' preliminary knowledge about the concept of energy can be identified through metaphors. As metaphors serve as an interface between different pieces of information in the mental structuring of scientific knowledge, they can be used in forming mental maps related to the concept of energy. These maps can be used to correctly define the concept of energy as well as to eliminate confusion related to the properties of energy and energy as it is taught during class time. Mental models that facilitate the comprehension of the concept of energy can be used to produce a definition of energy that is common across different disciplines.

Problem Situation

Since metaphor and empathy are abstract concepts, their definitions vary from person to person and according to scientific fields. Definitions are made using similar characteristics of different concepts, phenomena, relationships, events, etc. Since similar characteristics vary from person to person, it is difficult to create a common definition for abstract concepts. People in scientific fields express the same concept as a metaphor using mental processes according to different definitions or specific characteristics. Therefore, metaphor sheds light on how the mental structure is formed. In addition, the use of metaphor will contribute to a common definition of abstract concepts among scientific fields. In this context, the concept of energy is expressed with different metaphors in different fields of science. These expressions will enable the establishment of connections between scientific fields, the elimination of deficiencies and errors, and the establishment of correct and effective relationships between fields. It is important to establish a correlation between concepts in the mental structuring of abstract concepts. Determining the correlation between energy metaphor and empathic tendency is important in terms of mental structuring. Learning is realized by establishing connections between mental structures. Knowing the connections between concepts will enable learning to take place more effectively.

In this study, qualitative and quantitative relationships between the classification of energy metaphor according to traditional and scientific fields and the empathic tendency status and empathic tendency levels were examined. It was investigated whether there was a quantitative correlation between empathic tendency scores and traditional metaphor classes. A qualitative correlation between empathic tendency levels and the fields of science (categories) in which the energy metaphor is included was tried to be determined. The correlation between energy metaphor and empathy was determined with the following questions.

1- What are the traditional classes and categories of the metaphors produced by pre-service mathematics and science teachers for the concept of energy?
2- What are the empathic tendencies and empathic steps of pre-service mathematics and science teachers?
3- Is there a significant difference between empathic tendency scores according to the traditional Energy Metaphor type?

Research Methodology

In the study, a semi-structured form and an empathic disposition scale were used to determine metaphors for the concept of energy. Mathematics (40) and science (71) pre-service teachers took part in the study. The concept of energy is very common in the fields of physics, chemistry and biology in science. Therefore, pre-service science teachers were included more in the study.

The metaphors formed by the pre-service teachers for the concept of energy were categorized according to traditional and scientific fields. The empathic tendencies and empathic tendency steps of the pre-service teachers were determined. The correlation between the traditional metaphor classes and empathic tendency scores and the science fields (categories) in which the energy metaphor is included and the empathic tendency steps were determined.

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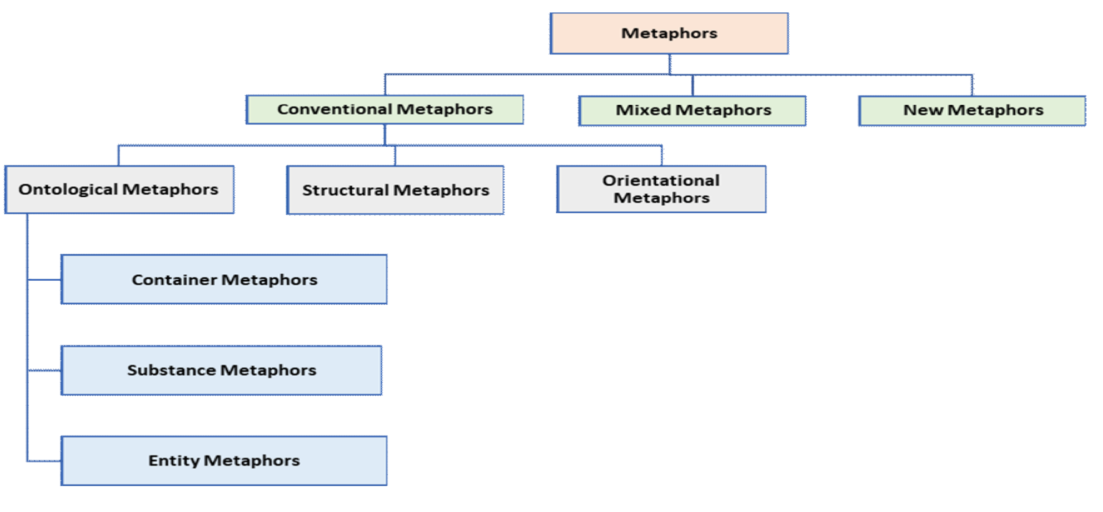
The importance of the study is that concrete and abstract concepts are used as metaphors to define abstract concepts. The metaphors produced for the concept of energy contribute to the determination and definition of the mental structuring of the concept of energy. The fields of science use the concepts, events and objects in their own fields of science to define the concept of energy. This means that each field of science produces metaphors for the concept of energy according to its own mental structuring. It is to define the concept of energy according to the fields of science. By using the energy metaphor, a common definition of energy between the fields of science is provided and the connections between the fields of science are strengthened. It will also contribute to the definition of a common energy concept that can be used by science fields to determine learning situations. In addition, determining the connection between the abstract concept of empathic tendency and energy metaphor will contribute to the more comprehensive mental structuring and definition of the concept of energy.

In the study process, candidates were given metaphors and examples of metaphors including the feature that connects the metaphor to the subject. While producing metaphors, it was emphasized that the metaphor alone would not make sense and that the feature linking the metaphor to the subject should be specified. A semi-structured form was created for the concept of energy and the pre-service teachers were asked to express their mental reflections about the concept of "energy" with another name using the form. The metaphors created for the concept of energy were obtained through content analysis. If the metaphor created for the concept of energy did not have energy-binding properties, it was considered invalid. The valid metaphors determined by the researchers were classified according to the traditional metaphors and science fields in Figure 1. The empathic tendency scale (Table 1) was used to determine the empathic tendency scores and empathic training stages of the teacher candidates. It was determined whether there was a quantitative correlation between traditional metaphor classes and empathic tendency scores. The fields of science (categories) in which the metaphors were created were compared with the empathic disposition levels.

In this study, metaphors related to the concept of energy were classified according to the traditional metaphor classification in the "Dictionary of Linguistic Terms" (SIL, 2018). The International Summer Institute of Linguistics (SIL, 2018) made a classification based on the work of Lakoff and Johnson (1980), Beekman and Callow (1974) and Mish (1991). This classification is given in Figure 1:

Figure 1
Classification of Metaphors. SIL. (2018)



Conventional metaphors: A conventional metaphor is commonly used in the colloquial language of a culture to give structure to part of the conceptual system of that culture. There are three different kinds of conventional metaphors: ontological, orientational, and structural. A structural metaphor is a conventional metaphor, whereby a concept is understood and expressed vis-à-vis another structured, sharply defined concept. Orientational metaphors involve orientations, such as space, place, inside, and outside, and are concerned with systematic relationships between emotions and motor-perceptual experiences. An ontological metaphor is a metaphor where an abstrac-

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tion, such as an activity, emotion, or idea, is represented by something concrete, such as an object, substance, container, or person. There are three kinds of ontological metaphors: container, entity, and substance. Container metaphors are ontological metaphors in which some concepts are represented as having an inside and outside and capable of holding something else. Material metaphors are ontological metaphors in which an abstraction, such as an event, activity, emotion, or idea, is represented as material. Entity metaphors are ontological metaphors in which an abstraction is represented as a concrete physical object (SIL, 2018).

Mixed metaphors: Mixed metaphors are used to express the same concept, used in the same utterance, especially in the same sentence. In other words, it involves expressing a concept in a sentence using different metaphors. Mixed metaphors often, but not always, lead to a clash of concepts.

New metaphors: New metaphors are not part of a culture's conceptual system as reflected in its language. This is defined as allegory (SIL, 2018). Allegories are metaphors extendable as stories, especially used to make sense of and express aspects of fictional characters, actions, and concepts related to human existence (Kurt, 2019).

The empathetic tendencies of pre-service teachers were measured using the empathic tendency scale developed by Dökmen (1988) in Table 1. The scale is Likert type and consists of 20 question statements about empathic tendency. The lowest score that can be obtained from the scale is 20 and the highest score is 100. The highest score for each item is 5 and the lowest score is 1.

Table 1
The Empathic Tendency Scale (Dökmen, 2018)

	Empathic tendency questions	Strongly Disagree (1)	I agree very little (2)	Sometimes I agree (3)	Usually I agree (4)	Completely I agree (5)
1	I have many friends.	( )	( )	( )	( )	( )
2	Sometimes I get teary-eyed while watching a movie.	( )	( )	( )	( )	( )
3	I often feel lonely.	( )	( )	( )	( )	( )
4	Those who talk to me about their problems feel relieved after our conversation.	( )	( )	( )	( )	( )
5	The problems of others concern me as much as my problems.	( )	( )	( )	( )	( )
6	I have difficulty communicating my feelings to others.	( )	( )	( )	( )	( )
7	I find it strange when people cry while watching a movie	( )	( )	( )	( )	( )
8	Sometimes, when I'm arguing with someone, my attention is more focused on my answer than on what the other person is saying.	( )	( )	( )	( )	( )
9	I am a very popular person in my social circle.	( )	( )	( )	( )	( )
10	I feel relieved when movies have a happy ending.	( )	( )	( )	( )	( )
11	I have difficulty communicating my thoughts to others.	( )	( )	( )	( )	( )
12	Most people are selfish.	( )	( )	( )	( )	( )
13	I'm an angry person.	( )	( )	( )	( )	( )
14	I usually trust people.	( )	( )	( )	( )	( )
15	People don't completely understand me.	( )	( )	( )	( )	( )
16	I'm a sociable person.	( )	( )	( )	( )	( )
17	It makes me feel better to open up to someone close to me about my problems.	( )	( )	( )	( )	( )
18	I am generally satisfied with my life.	( )	( )	( )	( )	( )
19	My close ones often tell me about their problems.	( )	( )	( )	( )	( )
20	I'm usually in a good mood.	( )	( )	( )	( )	( )

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A high total score indicates a high level of empathetic tendency; a low score indicates a low empathetic tendency. Using the medians of each empathic tendency statement in the scale, the ranking of the empathetic tendency levels was determined. Mean empathic tendency scores vary between 1 and 5. According to the mean empathic scores, the empathic disposition behaviors of the pre-service mathematics and science teachers were ranked. According to this ranking, empathic disposition classes were determined.

The metaphors about the concept of energy created by pre-service mathematics and science teachers were traditionally classified and categories were formed. Empathic tendency scores and average empathic scores of the candidates were calculated. Mann Witney-U test was used in the comparison of the traditional classifications of the metaphors formed by the candidates and their empathic tendency scores, since normality and homogeneity of variance were not ensured.

Data Collection

In the semi-structured form, sample metaphors were presented, and the pre-service teachers were asked to examine them. The pre-service teachers were asked to write a metaphor for and a property of the concept of energy in the blanks in the form. In the form, the first blank is for the source of the metaphor, and the second blank is for the property associated with the concept. Below is the template used by the pre-service teachers.

Energy is .... (source of the metaphor)....... *Because*......(the property that links the metaphor to the concept).....

The metaphors produced in accordance with the template were classified traditionally in Figure 1 and Table 2 and Table 3 of pre-service mathematics and science teachers were created. In addition, the fields of science in which the energy metaphors took place are shown in Figure 2 and Figure 3.

The empathic disposition levels of the pre-service teachers were measured using the 20-item "empathetic disposition scale" (Table 1) developed by Dökmen (1988). Each question was answered on a Likert scale from 1 to 5, the lowest and the highest scores that can be obtained from an item, respectively. The 3rd, 6th, 7th, 8th, 11th, 12th, 13th, and 15th items were reverse scored. Based on the scores obtained from the scale, the pre-service teachers' empathetic tendency scale scores and the mean scores of the items were determined.

Data Analysis

The metaphors for the concept of energy and the features linking the metaphor to the source subject were obtained using a semi-structured form. The energy metaphor was created by passing the data through the following stages (Saban, 2009).

1- Coding and sorting: The data obtained through the semi-structured form were coded and sorted, and the metaphors developed by the participant teachers for the concept of energy and the associated property that links the metaphor to the subject were determined.
2- Sorting and presenting valid metaphors in a table: The metaphors the pre-service teachers developed were classified under the respective types of conventional metaphors and tables were created accordingly.
3- Categorization: The valid metaphors were categorized by their characteristics.
4- Validity and reliability: Appropriate sample metaphors, instructions on what the metaphors should entail, the purpose of the study, and information about the concept of metaphors were laid out in a semi-structured form. The metaphors produced by the pre-service teachers about the concept of energy were examined by the researchers to check whether the metaphors and the associated properties were consistent, and the inconsistent ones were removed.
5- Analysis of qualitative data: After the stages listed above, Table 2 and Table 3 were created, which contain the metaphors, the number of each metaphor, and the classification of the metaphors under types of conventional metaphors. In addition, the distribution of energy metaphors in Table 2 and Table 3 according to science fields (categories) are given in Figure 1 and Figure 2.

The data on empathic tendency consisted of the mean item scores and total scores of the pre-service teachers on the empathic tendency scale (Table 1). The mean and total scores of each item were found separately for 20 question items. Means were found for each question in Table 1 and are presented in Table 4 and Table 5. The sum of the mean scores constituted the empathic tendency scores of pre-service mathematics and science teachers.

The empathic disposition score corresponding to the traditional classification of the energy metaphor created

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by each pre-service teacher was determined (Table 6 and Table 8). The averages of the empathic tendency scores of the candidates who produced a common energy metaphor were taken. The traditional ontology metaphor 1 was represented by the structural metaphor 2 and the correlation between metaphor and empathic disposition was determined using the Mann-Whitney U test. The test results are listed in Table 7 and Table 9.

The findings are presented under three sub-sections: the categorization of the metaphors and their classification under different types of conventional metaphors, pre-service teachers' empathetic tendency levels, and the correlation between different types of metaphors and levels of empathetic tendency.

Research Results

The classification of the pre-service teachers' metaphors for the concept of energy under different types of conventional metaphors and the categorization of the metaphors were made separately for mathematics and science pre-service teachers. Findings on the classification of the pre-service teachers' metaphors for the concept of energy under different types of conventional metaphors and the categorization of the metaphors. Results related to the metaphors created for the concept of energy are presented separately for pre-service mathematics and science teachers. The metaphors developed and their classification under two traditional metaphor types are given in Table 2 and Table 3. Categories are created according to the metaphors in Table 2 and Table 3.

The findings related to the empathic disposition levels of the participating pre-service mathematics and pre-service science teachers are given in Table 4 and Table 5. In the tables, empathic disposition scale items, mean scores for each item, and total scores are given. Total scores were obtained by summing the average score of each question item.

Findings on the correlation between the classification of pre-service teachers' metaphors about the concept of energy under traditional metaphor types and pre-service teachers' empathic tendency levels. Table 6 and Table 8 were created based on the data in Table 2 and Table 3, in which the participant pre-service teachers' metaphors about the concept of energy were classified under different traditional metaphor types. Using these tables, the correlation between the metaphors classified as traditional and empathic tendency scores was determined using the SPSS software program. Since empathic tendency scores did not show normal distribution, Mann-Whitney U test was used, and the test results are given in Table 7 and Table 9.

Traditional Classification of Energy Metaphors Produced by Pre-Service Mathematics Teachers.

The pre-service mathematics teachers produced 40 metaphors for the concept of energy. The main concepts used by these pre-service teachers in creating metaphors were vitality and life (Table 2). These metaphors are classified as structural (n = 27) and ontological (n = 13) (entity) metaphors.

Table 2
Traditional Classification of Energy Metaphors Generated by Pre-service Mathematics Teachers

Metaphor for energy	*N*	Kind of conventional metaphor	Metaphor for energy	*N*	Kind of conventional metaphor
Vitality	7	Structural	Motivation	1	Structural
Life	4	Structural	A book	1	Ontological (Entity)
Food	2	Ontological (Entity)	Entrepreneurship	1	Structural
Water	2	Ontological (Entity)	A need	1	Structural
Movement	2	Structural	Power	1	Structural
A mischievous child	2	Ontological (Entity)	A radiator	1	Ontological (Entity)
Happiness	2	Structural	Breathing	1	Structural
A cake	1	Ontological (Entity)	Nutrition	1	Ontological (Entity)
A child	1	Ontological (Entity)	Playing a game	1	Structural
An emotion	1	Structural	Walking	1	Structural

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Metaphor for energy	N	Kind of conventional metaphor	Metaphor for energy	N	Kind of conventional metaphor
A friend	1	Structural	A daily activity	1	Structural
Joy	1	Structural	A state of mind	1	Structural
The sun	1	Ontological (Entity)	A tree	1	Ontological (Entity)
				Total = 40	

5 Below is the categorization of the metaphors presented in Table 1,

Energy as the perpetuity of life: The metaphors under this category are life (n=4), food (*n* = 2), water (*n* = 2), happiness (*n* = 2), cake (*n* = 1), child (*n* = 1), emotion (*n* = 1), friend (*n* = 1), joy (*n* = 1), motivation (*n* = 1), book (*n* = 1), entrepreneurship (*n* = 1), need (*n* = 1), breathing (*n* = 1), food (*n* = 1), playing a game (*n* = 1), daily activity (*n* = 1), and state of mind (*n* = 1). A total of 24 metaphors fell under this category, and in their metaphors, the said pre-service teachers used the concept of life the most.

Energy as an aspect of the science of biology: Eight metaphors fell under this category, including vitality (*n* = 7) and tree (*n* = 1).

Energy as an aspect of the science of physics: Six metaphors fell under this category, including movement (*n* = 2), a mischievous child (*n* = 2), power (*n* = 1), and walking (*n* = 1).

Energy as an energy source*:* Two metaphors fell under this category, namely, sun (*n* = 1) and radiator (*n* = 1).

Figure 2
Distribution of Energy Metaphors Produced by Mathematics Teacher Candidates by Science Fields (categories).

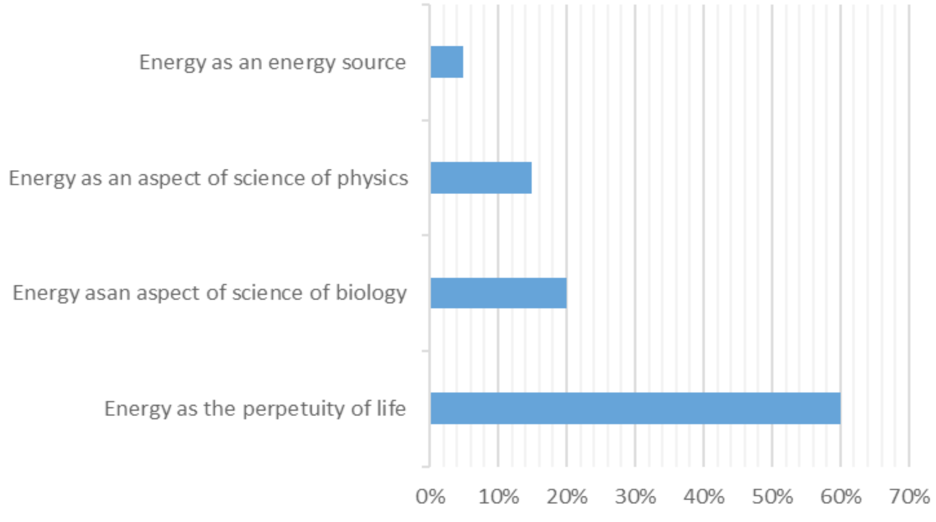

Figure 2 shows the distribution of the metaphors produced by pre-service mathematics teachers for the concept of energy according to their fields of science.

Traditional Classification of Energy Metaphors Generated by Pre-service Science Teachers

The pre-service science teachers produced 71 metaphors for the concept of energy. The main concepts used by these pre-service teachers in creating metaphors were water, existence, money, mobility, food, and friends in generating metaphors for the concept of energy (Table 3). These metaphors are classified as structural (*n* = 40) and ontological (*n* = 31) (entity) metaphors.

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Table 3
Traditional Classification of Energy Metaphors Formed by Pre-service Science Teachers

Metaphor for energy	*N*	Kind of conventional metaphor	Metaphor for energy	*N*	Kind of conventional metaphor
Water	6	Ontological (Entity)	An emotion	1	Structural
Existence	6	Structural	Reunion	1	Structural
Money	6	Ontological (Entity)	A telephone	1	Ontological (Entity)
Movement	5	Structural	Dessert	1	Ontological (Entity)
Food	4	Ontological (Entity)	Open-air	1	Structural
A friend	3	Structural	Joy	1	Structural
Vitality	2	Structural	Walking	1	Structural
Standing	2	Structural	A need	1	Structural
Happiness	2	Structural	Power	1	Structural
Work	2	Structural	Effort	1	Structural
Light	2	Ontological (Entity)	Motivation	1	Structural
Doing work	2	Structural	An atom	1	Ontological (Entity)
Nutrition	1	Ontological (Entity)	A wave	1	Ontological (Entity)
Life	1	Structural	The Universe	1	Structural
Electricity	1	Ontological (Entity)	Indestructible	1	Structural
Fuel	1	Ontological (Entity)	Infinite	1	Structural
A factory	1	Ontological (Entity)	Diddling	1	Structural
A machine	1	Ontological (Entity)	Human	1	Ontological (Entity)
The sun	1	Ontological (Entity)	Moving	1	Structural
A battery	1	Ontological (Entity)	Transformation	1	Structural
Matter	1	Ontological (Entity)			
				Total = 71	

Below is a categorization of the metaphors presented in Table 2.

Energy as the perpetuity of life: The metaphors under this category are water (*n* = 6), existence (*n* = 6), money (*n* = 6), food *(n* = 4), friend (*n* = 3), happiness (*n* = 2), work (*n* = 2), nutrition (*n* = 1), life (*n* = 1), factory (*n* = 1), machine (*n* = 1), emotion (*n* = 1), reunion (*n* = 1), telephone (*n* = 1), dessert (*n* = 1), open-air (*n* = 1), joy (*n* = 1), need (*n* = 1), effort (*n* = 1), and motivation (*n* = 1). A total of 42 metaphors fell under this category, and in their metaphors, the said pre-service teachers used the concepts of water, existence, and money the most.

Energy as an aspect of the science of physics: A total of 16 metaphors fell under this category, including movement (*n* = 5), standing (*n* = 2), doing work (*n* = 2), walking (*n* = 1), power (*n* = 1), the universe (*n* = 1), indestructible (*n* = 1), infinite (*n* = 1), diddling (*n* = 1), and moving (*n* = 1).

Energy as an energy source: A total of 16 metaphors fell under this category, including light (*n* = 2), electricity (*n* = 1), fuel (n = 1), sun (*n* = 1), battery (*n* = 1), and wave (*n* = 1).

Energy as an aspect of the science of biology: Three metaphors fell under this category, including vitality (*n* = 2) and human (*n* = 1).

Energy as an aspect of the science of chemistry and physics*:* Three metaphors fell under this category, namely matter (*n* = 1), atom (*n* = 1), and transformation (*n* = 1).

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Figure 3
Distribution of Energy Metaphors Produced by Pre-service Science Teachers According to Science Fields (category)

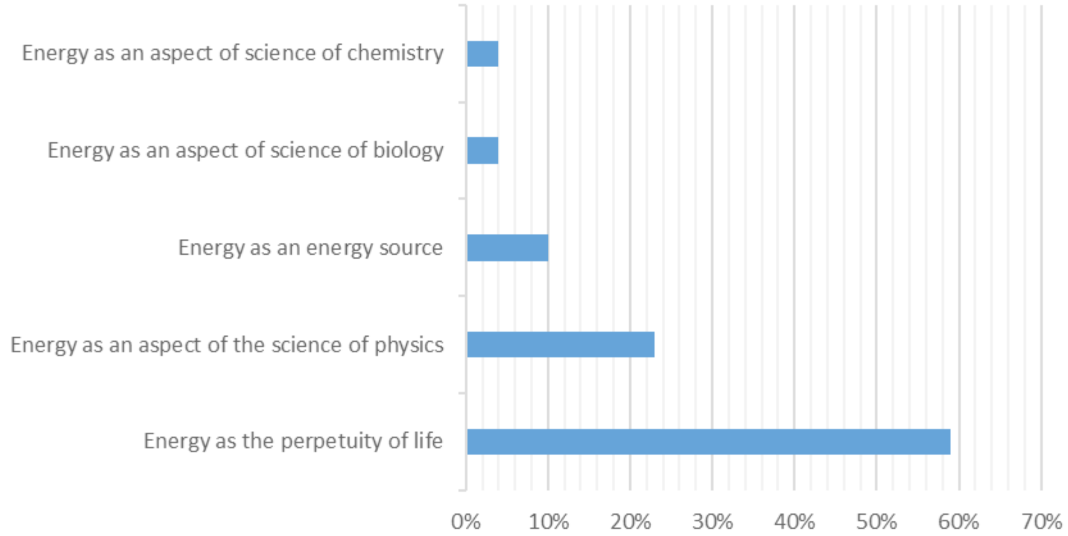

Figure 3 shows the distribution of the metaphors produced by pre-service science teachers for the concept of energy according to their fields of science.

The categorical distributions of energy metaphors created by pre-service mathematics and science teachers are similar. Unlike science teachers, mathematics teachers predominantly produced metaphors in the category of chemistry and physics. While 41% of the metaphors produced by science teachers were related to science (Figure 3), this rate was 40% for mathematics teachers (Figure 2). Pre-service mathematics and science teachers produced the most metaphors in the category of the perpetuity of life (60% and 59%, respectively).

Empathic Tendency Levels of Pre-service Mathematics Teachers

The responses of the pre-service mathematics teachers to the statements in the empathetic tendency scale were ranked from the one with the highest mean score to the one with the lowest. The closer the mean score to 5 the higher the level of empathetic tendency.

As seen in Table 4, the total of the mean scores pre-service mathematics teachers obtained from the items of the empathic tendency scale was found to be 69.57. The participant pre-service mathematics teachers were found to exhibit a high level of empathetic tendency. The items whose mean scores are between 3.72 and 4.17 showcase a high level of empathetic tendency. These items are related to helping others and solving others' problems, which are, according to the stages of empathy proposed by Dökmen (1988), associated with the you stage. Individuals who respond at this stage show behaviors such as supporting others, addressing problems, repetition, and understanding deep feelings.

The items whose mean scores are between 3.15 and 3.70 showcase an above-moderate level of empathetic tendency (Table 4). Items that point to an above-moderate level of empathetic tendency are associated with the I stage of Dökmen's (1988) stages of empathetic tendency, meaning that individuals practice empathy with a self-centric approach. Individuals who respond at this stage make empathetic remarks such as "I feel" and "I think".

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Table 4
The Mean Scores of The Items of Empathic Tendencies of Pre-service Mathematics Teachers

Empathic tendency questions	Empathetic tendency statements (*n* = 40)	Average empathetic disposition scores
7	I find it strange when people cry while watching a movie	4.17
10	I feel relieved when movies have a happy ending.	3.91
5	The problems of others concern me as much as my problems.	3.9
4	Those who talk to me about their problems feel relieved after our conversation.	3.85
19	My close ones often tell me about their problems.	3.72
6	I have difficulty communicating my feelings to others.	3.7
3	I often feel lonely.	3.7
17	It makes me feel better to open up to someone close to me about my problems.	3.67
9	I am a very popular person in my social circle.	3.65
20	I'm usually in a good mood.	3.62
18	I am generally satisfied with my life.	3.42
8	Sometimes, when I'm arguing with someone, my attention is more focused on my answer than on what the other person is saying.	3.3
11	I have difficulty communicating my thoughts to others.	3.3
13	I'm an angry person.	3.25
16	I'm a sociable person.	3.22
2	Sometimes I get teary-eyed while watching a movie.	3.2
15	People don't completely understand me.	3.17
12	Most people are selfish.	3.05
1	I have many friends.	2.95
14	I usually trust people.	2.82
	Total	**69.57**

The items whose mean scores are between 2.82 and 3.05 showcase a moderate level of empathetic tendency (Table 4), which is associated with making friends, trusting, and selfishness. This level is associated with the they stage proposed by Dökmen (1988). Individuals who respond at this stage are concerned with what society (they) think or feel about an individual's problems. The most prevalent stage at which pre-service mathematics teachers respond is the you stage, followed by the I stage and the they stage.

Empathic Tendency Levels of Pre-service Science Pre-Service Teachers

The responses of the pre-service science teachers to the statements in the empathetic tendency scale were ranked from the one with the highest mean score to the one with the lowest.

As seen in Table 5, the total mean score pre-service science teachers obtained for the items of the empathic tendency scale was found to be 68.86. The participant pre-service science teachers were found to exhibit a high level of empathetic tendency. The items whose mean scores are between 3.91 and 4.02 showcase a high level of empathetic tendency. These items are related to helping and supporting others and solving others' problems, which are, according to the stages of empathy proposed by Dökmen (1988), associated with the you stage.

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Table 5
The Mean Scores of The Items of Empathic Tendencies of Pre-service Science Teachers

Empathic tendency questions	Empathetic tendency statements (*n* = 71)	Average empathetic disposition scores
5	The problems of others concern me as much as my problems.	4.02
4	Those who talk to me about their problems feel relieved after our conversation.	4.01
10	I feel relieved when movies have a happy ending.	3.97
7	I find it strange when people cry while watching a movie.	3.91
3	I often feel lonely.	3.85
9	I am a very popular person in my social circle.	3.85
19	My close ones often tell me about their problems.	3.83
6	I have difficulty communicating my feelings to others.	3.73
20	I'm usually in a good mood.	3.7
16	I'm a sociable person.	3.61
18	I am generally satisfied with my life.	3.4
2	Sometimes I get teary-eyed while watching a movie.	3.35
1	I have many friends.	3.25
11	I have difficulty communicating my thoughts to others.	3.22
17	It makes me feel better to open up to someone close to me about my problems.	3.19
13	I'm an angry person.	3.12
15	People don't completely understand me.	3.05
8	Sometimes, when I'm arguing with someone, my attention is more focused on my answer than on what the other person is saying.	2,78
12	Most people are selfish.	2.64
14	I usually trust people.	2,38
	Total	**68.86**

The items whose mean scores are between 3.12 and 3.85 showcase an above-moderate level of empathetic tendency. Items that point to an above-moderate level of empathetic tendency are associated with the I stage of Dökmen's (1988) stages of empathetic tendency, meaning that individuals practice empathy with a self-centric approach. The items whose mean scores are between 2.38 and 3.05 showcase a moderate level of empathetic tendency, which is associated with a lack of understanding of the other person, distrust, and selfishness This level is related to the tens level suggested by Dökmen (1988). The most common stage to which pre-service science teachers responded was the you stage, followed by the I stage and the they stage.

Relationship Between Traditional Energy Metaphors Constructed by Pre-service Mathematics Teachers and Their Empathic Tendencies

Table 6 shows the mean scores of the traditional energy metaphors and empathic tendencies of pre-service mathematics teachers. Ontological metaphors were coded as 1 and structural metaphors as 2. Since the mean scores of empathic tendencies did not show normal distribution, the correlation between metaphor and empathic tendency was found using Mann-Whitney *U* test.

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Table 6
Mathematics Teachers' Mean Empathic Tendency Scale Scores and the Types of Conventional Metaphors They Produced

Energy metaphor	*N*	Empathic tendency score	Kind of conventional metaphor	Energy metaphor	*N*	Empathic tendency score	Kind of conventional metaphor
Vitality	7	73.28	Structural	Motivation	1	46	Structural
Life	4	78	Structural	A book	1	80	Ontological(Entity)
Food	2	62	Ontological(Entity)	Entrepreneurship	1	46	Structural
Water	2	69	Ontological(Entity)	A need	1	78	Structural
Movement	2	69	Structural	Power	1	56	Structural
A mischievous child	2	73.5	Ontological(Entity)	A radiator	1	75	Ontological(Entity)
Happiness	2	61	Structural	Breathing	1	62	Structural
A cake	1	78	Ontological(Entity)	Nutrition	1	75	Ontological(Entity)
A child	1	63	Ontological(Entity)	Playing a game	1	80	Structural
An emotion	1	75	Structural	Walking	1	56	Structural
A friend	1	73	Structural	A daily activity	1	78	Structural
Joy	1	83	Structural	A state of mind	1	62	Structural
The sun	1	75	Ontological(Entity)	A tree	1	68	Ontological(Entity)

The results of the Mann-Whitney *U* test to compare the empathic tendency scores according to the traditional energy metaphor types created by the pre-service mathematics teachers are shown in Table 7. In this table, no statistically significant relationship was found between the scores of the empathic tendency scale according to the traditional metaphor types according to the Mann-Whitney *U* test results ($U = 174$; $p > .965$).

Table 7
Comparison of Pre-service Mathematics Teachers' Empathic Tendency Scores According to The Traditional Metaphor Types

Traditional metaphor types	*N*	*MR*	*SR*	*U*	*p*
Ontological (entity)	13	20.86	265	174	.965
Structural	27	20.56	555		

Not: Mean Ranks: *MR* and Sun of Ranks: *SR*

Relationship between Traditional Energy Metaphors Constructed by Pre-service Science Teachers and Their Empathic Tendencies

Table 8 shows the mean scores of pre-service science teachers' traditional energy metaphors and empathic tendencies. Ontological metaphors were coded as one and structural metaphors as 2. Since the mean empathic disposition scores were not normally distributed, the comparison of empathic tendency scores according to traditional metaphor types, according to Mann-Whitney *U* test.

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Table 8
Science Teachers' Mean Empathic Tendency Scale Scores and The Types of Conventional Metaphors They Produced

Energy metaphor	*N*	Empathic tendency score	Kind of conventional metaphor	Energy metaphor	*N*	Empathic tendency score	Kind of conventional metaphor
Water	6	65.5	Ontological(Entity)	An emotion	1	68	Structural
Existence	6	68.83	Structural	Reunion	1	67	Structural
Money	6	69.03	Ontological(Entity)	A telephone	1	63	Ontological(Entity)
Movement	5	71.8	Structural	Dessert	1	59	Ontological(Entity)
Food	4	62	Ontological(Entity)	Open-air	1	75	Structural
A friend	3	62.66	Structural	Joy	1	80	Structural
Vitality	2	73	Structural	Walking	1	74	Structural
Standing	2	76.5	Structural	A need	1	78	Structural
Happiness	2	65.5	Structural	Power	1	80	Structural
Work	2	68.5	Structural	Effort	1	68	Structural
Light	2	69	Ontological (Entity)	Motivation	1	65	Structural
Doing work	2	69.5	Structural	An atom	1	63	Ontological(Entity)
Nutrition	1	68	Ontological(Entity)	A wave	1	74	Ontological(Entity)
Life	1	59	Structural	The Universe	1	82	Structural
Electricity	1	83	Ontological(Entity)	Indestructible	1	47	Structural
Fuel	1	78	Ontological(Entity)	Infinite	1	79	Structural
A factory	1	80	Ontological(Entity)	Diddling	1	80	Structural
A machine	1	78	Ontological(Entity)	Human	1	78	Ontological(Entity)
The sun	1	77	Ontological(Entity)	Moving	1	76	Structural
A battery	1	56	Ontological(Entity)	Transformation	1	61	Structural
Matter	1	58	Ontological(Entity)				

Table 9 shows the results of the Mann-Whitney *U* test, which was conducted to compare the scores of empathic tendencies according to traditional energy metaphors created by pre-service science teachers. According to this table, when the scores of the empathic disposition scale were compared with the traditional metaphor types produced by the pre-service teachers, there was no statistically significant difference on the empathic disposition scale score of the metaphor generation type ($U = 527.5$; $p > .282$).

Table 9
Comparison of Pre-service Science Teachers' Empathic Tendency Scores According to the Traditional Metaphor Types

Traditional metaphor types	*N*	*MR*	*SR*	*U*	*p*
Ontological (entity)	31	33.02	1023.50	527.50	.282
Structural	40	38.31	1532.50		

Note: Mean Ranks: *MR* and Sun of Ranks: *SR*

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Discussion

Mathematics and science teachers produced metaphors for the concept of energy by using abstract and concrete concepts. The metaphors produced were in the structural and ontological (entity) metaphor class in the traditional classification. The metaphors produced mostly consisted of structural and abstract concepts. Concrete objects and concepts were used as ontological metaphors.

Traditional Classification and Categorization of the Metaphors Produced by Pre-service Teachers for the Concept of Energy

The metaphors produced by pre-service mathematics teachers for the concept of energy were distributed as 27 structural and 13 ontological (being) metaphors according to the traditional metaphor classification. Pre-service science teachers distributed 40 structural and 31 ontological metaphors. While producing metaphors for abstract concepts, pre-service mathematics and science teachers mainly used structural metaphors. Pre-service mathematics teachers produced more structural metaphors than pre-service science teachers did.

Pre-service mathematics teachers predominantly expressed the abstract concept of energy using abstract concepts. These concepts, such as *vitality, life, and happiness*, are used in daily life. Lakoff and Johnson (2003) stated that structural metaphors have an important place in describing daily events. While pre-service mathematics teachers produced metaphors for the concept of energy, they used concepts such as interaction, *entrepreneurship, friend, need, play, playfulness,* and mood. Inam (2008) stated that structural metaphors are frequently used in daily life and communication. Pre-service mathematics teachers produced 13 ontological (being) metaphors by abstracting the abstract concept of energy. These metaphors are oriented toward daily needs and comprise concepts such as food, water, cake, and book. Ontological metaphors consist of concepts used to concretize abstract concepts (Akın, 2015).

The metaphors produced by pre-service mathematics teachers for the concept of energy were categorized as 60% *continuity of life*, 20% *biological science*, 15% *physical science*, and 5% *energy source* (graph 1). Pre-service teachers produced metaphors about the sustainability of life rather than lessons. Of the metaphors produced, 40% were related to lessons.

While producing metaphors for the concept of energy, pre-service science teachers predominantly used the structural metaphor (n=40). Structural metaphors *are* composed of abstract concepts oriented toward daily life, such as life, movement, friends, vitality, happiness, and living. Because energy is an abstract concept and there are differences between scientific and everyday energy perceptions, metaphors related to everyday concepts were predominantly produced. This emphasizes that students use terms related to the world they live in when trying to explain events or situations in science (Yürümezoğlu et al., 2009). Pre-service science teachers produced 31 ontological (being) metaphors by abstracting the abstract concept of energy. These metaphors generally consisted of concrete concepts related to daily needs, such as *water, money, food, food, sun, telephone, and dessert*. Candidates produced a low number of metaphors for science, such as *doing business, electricity, fuel, battery, matter, humans, atoms, and wave*s. Pre-service teachers used abstract concepts when expressing the abstract concept of energy. This is because the complex and abstract aspects of metaphors can be understood in more concrete, familiar, and easily imagined terms (Lancor, 2015; Refaie, 2001; Semino, 2008). According to conceptual theory, since conceptual systems are metaphorical, abstract concepts can be understood using concrete metaphors (Lakoff & Johnson, 2003). The human conceptual system is metaphorical, and it has been stated that abstract concepts can be understood through concrete concept metaphors (Lakoff & Johnson, 1980, 2003).

The metaphors produced by pre-service science teachers for the concept of energy were 59% *continuity of life*, 23% *physical science*, 10% *energy source*, 4% *biological science* and 4% *chemistry.* The metaphors created by the candidates for science courses constitute 41% of the total metaphors. The number of metaphorical expressions related to the concept of energy in the field of science was low. In a study, it was stated that students had a limited conceptual understanding of energy related to science lessons (Opitz et al., 2019). In general, the metaphors produced consisted of concrete and abstract phenomena necessary for human life.

Empathic Tendencies of Pre-service Mathematics and Science Teachers

The empathy tendency score of pre-service mathematics teachers was 69.57 and 68.86 for pre-service science teachers. According to the scores of the candidates, their empathetic tendencies can be said to be at a high level.

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Although the ranking of the expressions of empathic tendency of pre-service mathematics and pre-service science teachers according to the mean score is different, the same empathic tendency expressions are in the first place. The expressions of empathic disposition of pre-service mathematics and pre-service science teachers with the highest mean were expressions such as *supporting the other person, addressing their problems, and understanding their feelings*. The pre-service teachers experienced the emotions, thoughts, and perspectives of the other person from their point of view. Empathy is about one being permeated by the other's self as though one were taking part in the other's emotional state and experiencing the other's perspective and life (Zahavi & Overgaard, 2012). The pre-service teachers felt the other person's problem and emotion as their own and showed an empathetic tendency in this direction. These tendencies correspond to ***the you stage*** according to Dökmeni's (1998) classification of empathetic tendencies.

The expressions of empathic disposition that had the second-ranked mean for pre-service mathematics and science teachers were the expressions of empathetic disposition that included their feelings and thoughts. Candidates preferred empathetic expressions that emphasized their feelings and thoughts rather than those of the other person. Expressions of own feelings and thoughts correspond to *the I* step in the classification of empathetic tendencies. Pre-service mathematics and science teachers preferred empathetic disposition expressions such as what society thinks and feels in the face of their problems. These were empathetic expressions such as *selfishness, distrust, and lack of understanding*. These statements correspond to *the tens level* in the classification of empathic tendencies.

The Correlation between Traditional Classes of Metaphors Related to the Concept of Energy and Empathic tendencies

The correlation between the traditional metaphors created by pre-service mathematics and science teachers and their empathic tendency scores was found using Mann-Witney U test. It was determined that there was no statistically significant difference between the empathic tendencies of pre-service mathematics and science teachers and traditional metaphor classes. The empathetic dispositions of pre-service mathematics and pre-service science teachers were found to have the highest mean at the sen step and high empathetic disposition in the study. In the traditional metaphor classification of the pre-service teachers, structural metaphors were the most common. In addition, more than half of the total energy metaphors produced were in the category of continuity of life. If an inference is made from these, it can be that the candidates have a high level of empathetic tendencies, that the class of empathetic tendencies is the sen level, and that they mainly produced structural metaphors and categorically produced concrete and abstract metaphors for the continuity of life.

Conclusions and Implications

Abstract concepts such as energy and empathic disposition are difficult to define. The correct definition of abstract concepts contributes to increasing learning effectiveness and connections between disciplines. In order to define abstract concepts, common features of other concepts are used, and this is done through mental processes. Mental processes vary from person to person. It is important to use abstract concepts such as metaphor and empathic tendency to meet this change at a common point, which will contribute to determining mental structuring. In this study, the results of the 3 questions regarding the concepts of energy metaphor and empathic tendency are given in the following paragraphs.

Mathematics and science teachers produced metaphors for the concept of energy by using abstract and concrete concepts. The metaphors produced were classified as structural and ontological (being) metaphors in the traditional classification. The metaphors produced by the pre-service teachers are structural and consist of abstract concepts. Concrete objects and concepts were used as ontological metaphors.

Approximately 60% of the metaphors produced by pre-service mathematics and science teachers for the concept of energy were in the category of continuity of life. Approximately 40% of the metaphors produced were in the science categories. Biology is the prominent field focused on by pre-service mathematics teachers, while physics is the prominent field for pre-service science teachers. In generating metaphors for courses, pre-service mathematics teachers produced metaphors for biology science, while pre-service science teachers produced metaphors for physics science.

Pre-service mathematics and pre-service science teachers have an above-average (high-level) empathic disposi-

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tion and have the sen level as the empathic disposition level. Pre-service teachers feel the other person's problems and emotions as their own. Pre-service teachers look at events and situations from the other person's point of view.

No quantitatively significant difference was found between traditional metaphor types and empathic tendencies. It can be inferred from this that while the pre-service teachers' empathic tendencies were high and the "you" level was prominent while producing metaphors for the concept of energy, they produced structural metaphors from the concepts related to the sustainability of life the most.

Recommendations

Metaphors and empathy are abstract concepts and reflections of mental models. A contribution can be made to the determination of mental structuring by determining the models in empathy and metaphor formation. Metaphors can be used as learning outcomes in determining mental models and thoughts about the subject in education and training processes. As empathy and metaphors are reflections of mental models, they can be used in restructuring the educational process and learning outcomes. In addition, expressions of an empathetic disposition can be used in teacher-student interactions during the lesson. The concept of energy is used in different fields of science. Using metaphors to establish connections between branches of science, the connections between branches of science can be extended.

Declaration of Interest

The authors declare no competing interest.

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DETERMINING PRE-SERVICE SCIENCE TEACHERS' UNDERSTANDING ABOUT STEM EDUCATION

Gonca Keçeci

Abstract. *STEM education is included in education programs by many countries on a global scale. Pre-service teachers are also expected to apply STEM education in their future classrooms. The aim of the research was to determine how pre-service science teachers perceived STEM education, whether they adopted it or not, whether they thought of themselves as sufficient, and the environment and situations that affected their STEM experience. The understanding of the pre-service science teachers was tried to be determined before the theoretical STEM education, after the theoretical education and after the STEM application. The study group of the research consisted of a total of 66 pre-service teachers. Content analysis results of the interviews were carried out in three stages. It was found that there was no single STEM definition that pre-service science teachers agreed on. The training provided increased the STEM competency levels of pre-service science teachers. However, the majority of pre-service science teachers defined themselves as having intermediate competence in STEM education. Pre-service teachers adopt STEM education and believe that it will contribute to students. Pre-service science teachers had the most difficulty in disciplinary integration during the STEM theory and practice education. The most preferred model after both theoretical knowledge and application was the problem-based STEM model.*

Keywords: *content analysis, pre-service science teachers, STEM education, STEM understanding*

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Introduction

Today, as we are getting closer to completing the first quarter of the 21st century, the constant change in technology has required countries to adapt themselves to these changes. With every developing technology, new business areas emerge, creating the need for competent employment in these business areas. These obligations and needs have made it essential to raise future generations as individuals who can follow the ever-changing technologies and adapt. It has been noted that students who are expected to struggle with the ever-changing world problems with the integration of engineering in K-12 education will gain the advantage of contributing to their teamwork, communication skills and problem-solving skills (Brophy et al., 2008). At this point, STEM education, which aims to integrate science, technology, engineering and mathematics disciplines, has come to the fore with an interdisciplinary perspective. It has been suggested to create student-centered environments by integrating engineering with science standards (National Research Council [NRC], 2012). In order to popularize the approach led by the United States of America, recommendations for curriculum development in STEM fields have been made in published national reports (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine of the National Academies, 2007). Calls have been made to encourage the applications of the STEM approach in K-12 education, to direct students to careers in STEM fields, and to increase their success in these fields (NRC, 2011). The Next Generation Science Standards, which encourage engineering and scientific applications rather than rote teaching, have been adopted by many states in America (NRC, 2013). Various reports and research, that have adopted the STEM approach in other countries, have been published one after another (Bureau of Labor Statistics, 2020; European Commission, 2015; EU STEM Coalition, 2015; Ministry of Education & Research, 2010; Ministry of Education [MNE], 2016; SINTEF, 2011; The Organization for Economic Co-operation and Development [OECD], 2008; OECD, 2013; Turkish Industry and Business Association [TUSIAD], 2017). These reports, whose common point is to provide learning environments suitable for STEM understanding, are not easy to implement. Despite recommendations to use the STEM approach, it is unclear exactly what it represents

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(Herschbach, 2011). It is seen that STEM is interpreted differently. There are different definitions such as; STEM as an integrated learning and teaching approach that requires making connections between disciplines (Karatas, 2017); as a simple term replacing mathematics or science (Sanders, 2009); accepting the argument that the combining of two disciplines is enough (Kelley & Knowles, 2016). According to Honey et al. (2014), in STEM applications, one discipline is used more dominantly than the others, while the others are used as supportive. In STEM discipline integration, disciplines can also be used as interdisciplinary, transdisciplinary or multidisciplinary (Vasquez et al., 2013). Along with the different definitions of STEM education, another challenge awaiting practitioners is the use of different pedagogy practices (Dare et al., 2019). Problem-based STEM (Breiner et al., 2012; El Sayary et al., 2015; Dischino et al., 2011), project-based STEM (Capraro & Jones, 2013; Capraro & Slough, 2013; Han et al., 2015; Sahin, 2013), engineering design-based STEM (Billiar et al., 2014; Capobianco & Rupp, 2014; Guzey et al., 2016), STEM with 5E model (Bybee, 2019; Sanjaya, 2018) have been suggested to be used in the STEM approach. The STEM literacy levels of the teachers who will interpret the STEM approach, where there is such a diversity, are very important. Teachers have a great role to play in the trainings to be given for the STEM approach. It is necessary to develop teachers' understanding of integrating STEM disciplines in addition to their knowledge of the content, pedagogy and technology (Honey et al., 2014). Although teachers are expected to integrate STEM disciplines, they face a lack of information on how to do so (Dare et al., 2019; Ejiwale, 2013). There is more than one application for the integration of STEM disciplines and there is no single truth that teachers will use (Bybee, 2013; Johnson, 2012; Ring et al., 2017). This status makes it hard for teachers who want to include STEM education in their classrooms. Before applying STEM education, teachers need to understand, make sense of, and determine the appropriate model for their own understanding (Ring et al., 2017). In cases where teachers are not given the opportunity to think about their own STEM models and appropriate environments are not provided. It can be difficult for them to take an interdisciplinary perspective and understand the concept of integrated STEM correctly and can cause contradictions in their beliefs (Moore et al., 2014).

Research Problem

The STEM approach has also been received with interest in Türkiye. In the report arranged by the TUSIAD (2014), it is underlined that countries that want to improve economy and technology will need persons who have studied STEM disciplines. Afterwards, in the STEM education report issued by the Ministry of National Education (2016), it was pointed out that individuals with 21st-century skills would also direct the forthcoming of countries. It keynoted the importance of STEM education in transforming theoretical knowledge into product, practice, and innovative inventions. With the influence of these reports, studies on the STEM approach have gradually increased since 2014 (Akaygun & Aslan-Tutak, 2016; Akgunduz et al., 2015; Baran et al., 2016; Corlu, 2014; Karahan et al., 2015; Kececi et al., 2017; Marulcu & Hobek, 2014). With the applied science unit of the science course curriculum in 2017, the STEM approach, which has been previously given a start by private schools and institutions, took its place in the program. In the science curriculum for secondary schools organized in 2018, the applied science unit was abolished, and students were believed to assign a demand or problem from real life for the subjects in the units and make science, engineering and entrepreneurship practices (MNE, 2018). At this point, the biggest problem is that science teachers are caught unprepared for this situation and have difficulties in applying it (Blackley & Howell, 2015; Corlu et al., 2014). The surprise of teachers who have not been educated in any training on the STEM approach during their undergraduate education can be considered natural. Teachers who use STEM activities with their students during the education and training process should be competent in STEM education. How teachers comprehend STEM understanding, whether they embrace it or not, whether they see themselves as sufficient or not will directly affect the success of the program. However, teachers' studies on how teachers perceive STEM education are limited compared to STEM definition studies (Dare et al., 2019). Although pre-service teachers participated in STEM practices, it was found that they were not confident enough in describing STEM education (Bartels et al., 2019). Alan et al. (2019), in their study that aimed to support pre-service science teachers' integrated teaching knowledge through STEM applications, stated that pre-service teachers believed in the necessity of STEM education, but thought that discipline integration was not easy. When teachers' STEM awareness is increased before they start their profession, they are given the opportunity to establish their own understanding of STEM before the application. In this regard, this study aimed to determine the understanding of pre-service science teachers about STEM education.

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Research Focus

The lack of a single accepted definition of STEM education, which is globally accepted and tried to be integrated into curricula, is an important problem for teachers and pre-service teachers who are STEM practitioners. However, the goal of effective workforce and career planning in the STEM field, which is desired to be achieved with STEM education, is common. Using STEM for equipping future generations with skills such as communication, cooperation, entrepreneurship, critical thinking and problem-solving required by the 21st century is also a common goal of many countries. In this respect, knowing the STEM understanding of pre-service teachers who have not started the profession actively gives education policymakers the chance to make the necessary interventions. In the research, STEM education was determined as a phenomenon, and it was tried to determine how pre-service science teachers perceived STEM education, whether they adopted it, whether they saw themselves as sufficient, and the environment and situations that affected STEM experiences. In the research, pre-service science teachers first participated in the STEM theoretical training, which lasted for six weeks. The pre-service teachers, who were divided into groups after the theoretical training, prepared a STEM activity that they could implement with their students in the future according to a STEM understanding they chose, and a lesson plan on how to implement the activity. Pre-service teachers presented their activities and the STEM approach they adopted to their peers. Pre-service teachers in the role of listeners evaluated the activities of their peers in their individual diaries.

Research Aim and Research Questions

This research aimed to determine the understanding of STEM about STEM during the 14-week theoretical and applied STEM education processes of pre-service science teachers. In this research study, responses to the following questions were explored.

1. What is the STEM understanding of pre-service science teachers before theoretical education and before and after applied education?
2. Which STEM learning and teaching models do pre-service science teachers prefer to use?

Research Methodology

General Background

A phenomenological research design was used in the research. The goal of research using phenomenological design is to search for various ways people use to comprehend, comment on, or make sense of a certain phenomenon or a certain aspect of reality. With this search, meanings are revealed on facts and these meanings are classified according to categories (Çepni, 2010). In phenomenological research, it is tried to understand and describe how people perceive these experiences by examining their daily experiences. In this paper, STEM education was determined as a phenomenon and pre-service science teachers' understanding of STEM was researched. Analysis of personal text, focus meetings, conversations with participants, participant observation, action research and interviews can be used in phenomenological designs (Delve & Limpaecher, 2022). In this research, semi-structured interviews were used for collecting data. All pre-service science teachers participated on a voluntary basis. Interviews were carried out three times: before theoretical education, and before and after applied education.

Participants

The study, in which 49 female and 17 male pre-service teachers participated, was carried out at a state university in eastern Türkiye. The research was carried out within the content of the "Special Teaching Methods II course", in a 14-week period in the 2018-2019 education term. The study group was settled by the purposeful sampling method. The researcher can take as some sample individuals who he believes reflect the generality and fit the characteristics he has determined, depending on his own judgment in this method (Ural & Kılıç, 2011). All of the pre-service teachers participated in STEM education applications, in which models related to renewable energy were designed using educational Lego sets before the research. In addition, all of the pre-service teachers attend the school experience course. Criteria for the study group of the research were preferred because it is thought

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that more realistic comments will be received in terms of the fact that the pre-service teachers have completed the basic courses, they have STEM awareness, and they see the practices of the teaching profession in the real environment during the school experience lesson. While coding the pre-service teachers, the ordinal numbers of the students who took the course and the group numbers during the STEM applications were coded to be written one after the other. For example, "PT37" was written for the 37th pre-service teacher in the class list, then the group number was added as "G11" and coded as "PT37G11". The research process was explained to the pre-service teachers, and it was stated that there was a voluntary basis for the collection of data within the scope of the research. All of the participating pre-service teachers voluntarily agreed to take part in the research. However, there were 14 pre-service teachers (PT3G10, PT5G7, PT7G9, PT9G10, PT15G10, PT31G5, PT40G2, PT41G9, PT45G11, PT47G9, PT57G11, PT62G11, PT63G2, PT65G5) who could not be reached for the interviews in the last stage of the study because it was the end of the semester, and the pre-service teachers went to other provinces due to the holiday period. However, since the data were collected at the beginning and in the middle of the application, the pre-service teachers were not excluded from the study group.

Instrument and Procedures

Pre-service teachers attended the interactive training in the 2018-2019 academic year in a 14-week period, in which theoretical information about STEM theory and applications was given. STEM definitions, history of STEM, national and international reports on STEM, learning-teaching models used in STEM education and STEM application examples were shared with pre-service teachers during the six-week period. After the theoretical knowledge, the pre-service teachers were released to form their groups for the application phase. It has been suggested that they form groups of 5-6 people and that the number of male pre-service teachers (25%) is less than the number of female pre-service teachers (75%) so that they should be homogeneously distributed among the groups. However, at the end of the given week, the pre-service teachers formed 11 groups that were quite different from what was expected. The 66. pre-service teachers did not want to join any group and wanted to carry out their own study. The fact that the groups were formed in different numbers and features suggested that it may be due to the differentiation of the communication and cooperation skills of the pre-service teachers, and the groups formed were not intervened in order to monitor how the process would continue. The experiences of pre-service teachers, who are expected to do STEM applications with their students in their future classes, while implementing their own STEM projects in this process are thought to be very important. In addition, it is considered as an important gain that pre-service teachers have the chance to observe and evaluate different projects in the other groups. The groups constructed an instance lesson plan in line with the STEM understanding they adopted, carried out STEM applications, presented their projects to their peers, and defended the dimensions of STEM disciplines. Pre-service teachers appreciated and discussed the STEM practices presented by their peers in terms of whether they should be integrated into disciplines or not, in terms of the method used. The presentations of the pre-service teachers were completed with self, peer and teacher evaluations. Presentations were recorded in order to understand how the pre-service teachers' understanding of STEM was shaped and how the learned theoretical knowledge was reflected in practice. Pre-service teachers carried out 11 group and one individual STEM activities. In the implementation phase, where the pre-service teachers were expected to do a STEM project in which they integrated the disciplines with their groupmates, all groups, except Group 10 and PT66G12 (who worked individually) preferred to use sensor sets to integrate technology and content-based engineering (Blackley & Howell, 2015; Moore & Smith, 2014) have included the gains of software engineering by coding in accordance with the integration. The number of people in the groups formed and information on the teaching and learning models the groups adopted in STEM applications are in Table 1.

Table 1
Characteristics of the Groups Created

Group	Female	Male	Adopted STEM models
1	PT16, PT19, PT33, PT36, PT38	PT1	Project Based STEM
2	PT24, PT29, PT40, PT58, PT63	PT49	Design Based STEM

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Group	Female	Male	Adopted STEM models
3	PT12, PT32, PT34, PT56, PT59	PT22	Problem-Based STEM
4	PT6, PT18, PT25, PT50, PT52	PT30	Problem-Based STEM
5	PT31, PT39, PT54, PT65	PT4, PT8	Problem-Based STEM
6	PT10, PT14, PT28, PT37, PT60, PT53	PT2	Problem-Based STEM
7	PT5, PT11, PT48, PT55, PT61	PT42	Problem-Based STEM
8	PT23, PT27, PT44	-	Project Based STEM
9	PT13, PT17, PT35, PT41, PT46, PT47, PT64	PT7	Problem-Based STEM
10	PT15, PT20, PT21, PT43	PT3, PT9	Problem-Based STEM
11	-	PT26, PT45, PT51, PT57, PT62	Project Based STEM
12	PT66	-	Project Based STEM

When Table 1 is examined, it is shown that seven of the groups formed by the pre-service teachers consist of six people, one group consists of seven and one group consists of eight people. It is shown that all members of Group 11 are male, and all members of Group 8 are female pre-service teachers. On the other hand, it is shown that a pre-service teacher prefers individual work rather than collaborative group work. It is shown that four groups adopted project-based STEM, seven groups adopted problem-based STEM, and one group adopted an engineering-based STEM approach in their STEM activities.

The data of the study were gathered through semi-structured interviews participated on a voluntary basis of pre-service teachers. Interviews were carried out three times: before theoretical education, and before and after applied education. Interviews lasted between 10-30 minutes. The interviews of the pre-service teachers were recorded using a voice recorder with the authorization.

Data Analysis

Phenomenological data analysis stages, textural descriptions in which data are directly listed, important explanations and quotations are made to understand how the phenomenon is experienced, keywords are specified, expressions are specified within themes; structural descriptions, in which a description of the setting or context that influences the way participants experience the phenomenon; and the "essence" of the phenomenon is conveyed as composite descriptions (Moustakas, 1994). In this study, the data obtained from the interviews were coded, the data were categorized according to their similarities, the categories were associated with each other and supported by direct quotations from the interviews in order to understand how the pre-service teachers perceived STEM education, whether they adopted it or not, and whether they saw themselves as sufficient. To better understand the variation of the codes obtained from the qualitative interviews in three phases, they were required to use bar graphs to represent them graphically. In this respect, embedded quantitative analysis is included.

For the internal validity of the research, the prepared interview form was examined by two science education experts, read by three pre-service teachers, and evaluated in terms of intelligibility. Necessary arrangements have been made. A natural environment was tried to be created during the interviews, and the answers of the participants were confirmed by repeating. The data obtained are presented without modification. The coding made by the two researchers in categorizing the data was checked, the numbers of concurrence and disagreement were defined, and the reliability of the research was checked out using the formula of Miles and Huberman (1994) Reliability=consensus/(consensus+disagreement). A consensus (reliability) of 93% was achieved. For the credibility of the interviews, the researcher spent time with the participants throughout the process. The research process was explained, and it was stated that the data collection was on a voluntary basis within the scope of the research. Instead of participants' names codes were used.

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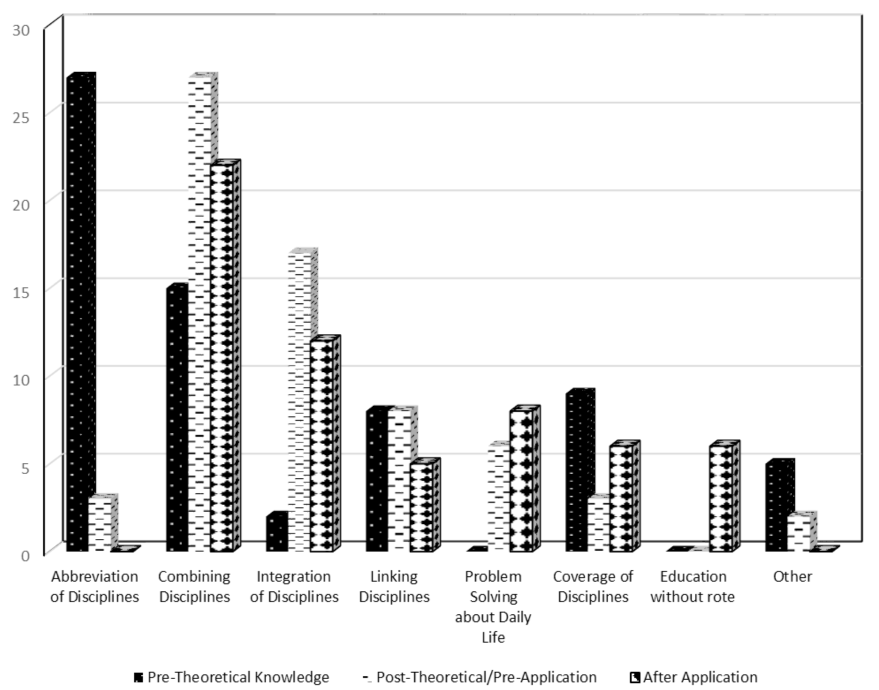
Research Results

In this study, STEM education was determined as a phenomenon, and it was tried to determine how science pre-service teachers perceived and adopted STEM education, whether they saw themselves as sufficient, their experiences, the environment and situations that affected their experiences. In the study, three-stage interviews were conducted with pre-service teachers. Findings from these interviews are given below.

In the study, pre-service science teachers were first asked to define STEM in order to understand the level of STEM comprehension of pre-service science teachers. It was tried to understand whether there were any changes in the definitions of pre-service teachers before and after theoretical knowledge and after the practical knowledge. Seven codes were determined according to the keywords used by the pre-service teachers. The definitions, which were not repeated and only said by a single pre-service teacher, were discussed under the eighth code title by creating the "Other" code. Six pre-service teachers (PT6G4, PT8G5, PT12G3, PT25G4, PT30G4, PT32G11) defined STEM with more than one word after the application. Therefore, these pre-service teachers were coded twice. STEM definitions of pre-service science teachers are given in Figure 1.

Figure 1
STEM Definitions of Pre-Service Science Teachers



At the beginning of the research, overall, the pre-service teachers were aware that the word STEM was the abbreviation of the initials of their discipline, but 27 pre-service teachers (41%) gave only the expansion of the abbreviation without any explanation. For example, the definition of PT7G9 at the beginning of the research is "*STEM is an abbreviation for science, technology, engineering, mathematics.*". All of the pre-service teachers participated in STEM education practices, in which models were designed through instructions on renewable energy using educational Lego sets before the research but did not receive theoretical information. Although STEM is not a concept that they first encountered, it can be said that the pre-theoretical definitions of pre-service teachers are quite superficial. The pre-service teachers (except for three pre-service teachers after theoretical knowledge; PT37G6, PT51G11, PT53G6) developed the definition of discipline abbreviation throughout the process and made changes in their definitions. After the application, all pre-service teachers moved away from using the term "*discipline abbreviation*" while defining STEM. While there were two pre-service teachers who defined STEM as the integration of disciplines at the beginning, it increased to 17 pre-service teachers (25%) after the theoretical knowledge and

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decreased to 12 pre-service teachers (18%) after the application. The definition of PT12G3 after the theoretical knowledge is as follows; *"STEM is an integrated approach to science, technology, engineering and mathematics. Art and entrepreneurship can also be integrated".* The fact that STEM integration definitions were given during the theoretical knowledge may have caused this situation. The decrease in the number of pre-service teachers who define STEM as discipline integration after the application may be due to the difficulties of pre-service teachers in disciplinary integration while developing an exemplary STEM activity. The majority of pre-service teachers defined STEM as the use of disciplines together. 15 pre-service teachers (22%) at the beginning, 27 pre-service teachers (41%) after the theoretical knowledge, and 22 pre-service teachers (33%) after the application explained STEM as using the disciplines together. For example, the opinion of PT18G4 at the end of the application; *"STEM is a system created by the combination of science, engineering, technology, and mathematics disciplines. It is set on a project or a design and gives students different perspectives and creativity instincts".* Although the definitions of "discipline integration" and "combining of disciplines" seem to be similar, pre-service teachers' definition of " combining of disciplines" was accepted that they thought that the disciplines of STEM should be given together but did not express their opinion on how. Discipline integration, on the other hand, has been accepted as a situation in which they have an idea about how the disciplines will be used. Eight (12%) at the beginning, eight (12%) after theoretical knowledge, and five (7%) post-practice pre-service teachers defined STEM as the "linking of disciplines". Six (9%) after theoretical knowledge and eight (12%) post-practice pre-service teachers defined STEM as "solving daily life problems". Nine (13%) before the theoretical education, three (4%) after the theoretical education, and six (9%) post-practice pre-service teachers explained STEM as a top discipline that covers the disciplines. After the application, six (9%) pre-service teachers stated STEM as an approach that takes the students away from rote learning. PT30G4 after the application; *"It is a program that is far from rote learning, which is formed by the coming together of branches such as mathematics and engineering, where students gain experience by using the topics they have learned in the theoretical lessons with different applications",* he defined STEM. No such definition has been found before and after theoretical knowledge. The definitions coded as "Other", which were not repeated and only said by one pre-service teacher, were five (7%) at the beginning of the research, and two (3%) different definitions after theoretical knowledge. Before the theoretical knowledge, "engineering in science class", "education with Legos", "group work", "student-centered lesson", and "education given in private schools"; After the theoretical knowledge, definitions were made as "transfer of knowledge" and "open-ended course". No different definitions were found after the application. In practice, no relationship was found between the group they were in and their individual definitions of the pre-service teachers, who formed 12 different groups.

Pre-service teachers were asked whether they felt competent about STEM education. The responses were collected under three themes as being fully competent in STEM education, partially competent in STEM education, and not being competent in STEM education. While analyzing the data, percentage values were taken as a basis due to the decrease in the number of pre-service teachers who participated in the post-application interviews. An understanding of pre-service science teachers on STEM competencies is given in Table 2.

Table 2
Understanding of Pre-service Science Teachers on STEM Competencies

Themes	Codes	
Fully competent	Predicting what can be done in the STEM	Pre-Theoretical Knowledge PT13G9, PT21G10, PT24G2, PT33G1 Post-Theoretical Knowledge PT13G9, PT14G6, PT21G10, PT24G2, PT29G2, PT33G1, PT34G3, PT36G1, PT40G2, PT43G10 After Application PT14G6, PT24G2, PT43G10, PT55G7
	Be able to use STEM	Pre-Theoretical Knowledge PT10G6, PT44G8, PT54G5, PT60G6, Post-Theoretical Knowledge PT10G6, PT12G3, PT44G8, PT54G5, PT60G6, PT63G2 After Application PT10G6, PT23G8, PT28G6, PT35G9, PT38G1
	Being in the middle of STEM	Pre-Theoretical Knowledge PT64G9 Post-Theoretical Knowledge PT11G7, PT64G9 After Application PT4G5, PT8G5, PT56G3, PT64G9

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Themes	Codes	
Partially competent	Feeling moderately competent	Pre-Theoretical Knowledge PT3G10, PT9G10, PT11G7, PT14G6, PT17G9, PT20G10, PT29G2, PT36G1, PT63G2 Post-Theoretical Knowledge PT3G10, PT9G10, PT17G9, PT20G10, PT46G9, PT48G7, PT50G4, PT66G12 After Application PT17G9, PT20G10, PT44G8, PT46G9, PT48G7, PT50G4, PT66G12
	Finding deficiencies, feeling the need for improvement	Pre-Theoretical Knowledge PT2G6, PT4G5, PT12G3, PT15G10, PT18G4, PT23G8, PT25G4, PT35G9, PT39G5, PT40G2, PT41G9, PT43G10, PT49G2, PT52G4, PT55G7, PT56G3, PT57G11, PT58G2, PT59G3, PT62G11 Post-Theoretical Knowledge PT2G6, PT4G5, PT5G7, PT15G10, PT18G4, PT19G1, PT23G8, PT25G4, PT28G6, PT30G4, PT32G3, PT35G9, PT38G1, PT39G5, PT41G9, PT49G2, PT52G4, PT55G7, PT56G3, PT57G11, PT58G2, PT59G3, PT61G7, PT62G11 After Application PT2G6, PT12G3, PT13G9, PT18G4, PT19G1, PT21G10, PT22G3, PT29G2, PT32G3, PT34G3, PT36G1, PT39G5, PT49G2, PT52G4, PT54G5, PT58G2, PT59G3, PT61G7
	Be proficient in some disciplines	Pre-Theoretical Knowledge PT7G9, PT26G11, PT27G8, PT30G4, PT34G3, PT50G4, PT51G11, PT53G6 Post-Theoretical Knowledge PT6G4, PT7G9, PT16G1, PT26G11, PT27G8, PT30G4, PT45G11, PT51G11, PT53G6, PT65G5 After Application PT6G4, PT16G1, PT26G11, PT27G8, PT30G4, PT33G1, PT51G11, PT53G6
Not being competent	Being at the beginning of STEM education	Pre-Theoretical Knowledge PT5G7, PT6G4, PT8G5, PT19G1, PT26G11, PT28G6, PT30G4, PT32G3 PT37G6, PT38G1, PT42G7, PT45G11, PT46G9, PT48G7, PT57G11, PT61G7 Post-Theoretical Knowledge ÖA8G5, PT26G11, PT22G3, PT37G6, PT42G7, PT57G11 After Application PT11G7, PT25G4, PT37G6, PT42G7, PT60G6,
	Feeling distant from STEM education	Pre-Theoretical Knowledge PT1G1, PT16G1, PT22G3, PT47G9, PT65G5, PT66G12 Post-Theoretical Knowledge PT1G1, PT47G9 After Application PT1G1

Three codes were formed from the data collected under the theme of being fully competent in STEM education. The answers of the pre-service teachers were gathered under the headings of predicting what I can do in the STEM field, being able to use STEM, and being in the middle of STEM. The percentage of pre-service teachers who stated that they were competent in STEM; 13% in pre-theoretical interviews, 27% in post-theoretical interviews, and 23% in post-application interviews. When the data are examined, it is understood that the percentage of pre-service teachers who find themselves competent in STEM increased after the theoretical knowledge but decreased again after the application.

Three codes were formed from the data collected under the theme of being partially competent in STEM education. The answers of the pre-service teachers were grouped under the headings of feeling moderately competent, feeling lacking and needing improvement, and being proficient in some disciplines. The percentage of pre-service teachers who stated that they were partially competent in the STEM field; 56% in pre-theoretical interviews, 63% in post-theoretical interviews, and 63% in post-application interviews. When the data are examined, it is understood that the percentage of pre-service teachers who find themselves partially competent increased after the theoretical knowledge and did not change after the application.

Two codes were formed from the data collected under the theme of not being competent in STEM education. The answers of the pre-service teachers were gathered under the headings of being at the beginning of STEM education and feeling distant from STEM education. The percentage of pre-service teachers who stated that they were not competent in the STEM field is 36% in the pre-theoretical interviews, 12% in the post-theoretical interviews, and 11% in the post-application interviews. When the data are examined, it is understood that the percentage of pre-service teachers who do not find themselves competent decreased after the theoretical knowledge. The percentage values before and after the application changed little.

Examples of pre-service teachers' views on their competencies in the STEM field are given.

PT13G9 felt competent at the beginning of the research under the influence of the training she attended; *"I participated in STEM education using Lego sets. If I have similar sets, I can also practice STEM education with my students"*. She is confident about STEM even though her statements after theoretical knowledge have changed; *"By combining STEM with entrepreneurship, I can help students see and evaluate future opportunities"*. After the application, she stated that she had superficial knowledge; *"I find myself at a superficial level and incomplete in terms of the fact that STEM education is new, and it is a concept and education that I have just seen"*.

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PT1G1 stated that he was far from STEM education in all interviews from the beginning of the research. His opinion in the post-application interview; *"I find myself far from STEM education. Since it is a model, we bought from abroad, I think it will be difficult to adapt it. But I also accept this fact; successful scientists worked in all subjects, that is, in at least 4-5 fields."*

The opinion of PT26G11, one of the pre-service teachers stated that he was competent in some disciplines; *"I consider myself more competent in the field of science. I feel weak in the fields of mathematics and technology"*. The opinion of ÖA53G6 is; *"I think I am good in science, technology and math. But I think I'm more lacking in the engineering part in practice, we had difficulties as a team in the engineering discipline."*

In order to understand whether pre-service science teachers have adopted STEM education, they were asked if they believed in STEM education. All of the pre-service teachers stated that they believed in STEM education in all three stages and answered the question by explaining the possible contributions of STEM education. The answers given by the pre-service teachers and their answers to the possible contributions of STEM education were examined under two themes as contribution to the student and contribution to the society. The codes formed under the theme of contribution to the student were divided into categories under the title of cognitive change, affective change and change in skills. No categories have been created for codes under the theme of contribution to society. The themes, codes and categories of the data obtained in all three stages of the research are given in Table 3.

Table 3
Themes, Codes and Categories Obtained from The Understanding of Pre-Service Teachers About the Contributions of STEM Education

Theme	Category	Codes
Contribution to the student	Change In Skills	Skill Development
		21st Century Skills
		Problem Solving Skill
		Creativity
		Innovative Idea / Innovation
		Entrepreneurship
		Critical Thinking
		Collaboration
		Communication
		Design Skill
	Cognitive Change	Increases Achievement, Knowledge Increase and Transfer
		Persistence in Knowledge, Avoids Rote Learning
		Diverse/Interdisciplinary Perspective
		Increase in Science Knowledge
		Increase in Technology Knowledge
		Increase in Engineering Knowledge
		Increase in Mathematics Knowledge
	Affective Change	Increased Curiosity
		Develops Imagination
Contribution to Society	-	Individuals Compatible with The Developing World
		It Meets the Need of Qualified/Producer People
		Connects Daily Life Problems
		Affects Career Choice

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The first category created under the theme of contribution to students is the category of change in skills. Pre-service teachers stated that STEM activities would change students' skills in all three stages. In cases where it was stated that STEM activities would contribute to students' skills but did not specify what these skills were, the data were collected under the "skill development" code. Similarly, the data stating that STEM activities contribute to students' 21st-century skills and that these skills are not specified are also stated as "21st-century skills" were collected under the code. 51 pre-service teachers before the theoretical knowledge, 14 pre-service teachers after the theoretical knowledge, and one pre-service teacher after the application stated that STEM activities would improve the skills. For example, before the theoretical knowledge, PT33G1 explained the contribution of STEM as *"STEM education allows students' skills to develop."*. After the theoretical knowledge, *"STEM education brings the characteristics of individuals such as critical thinking, problem-solving, being creative and self-directed."* stated the skills by name. After the application, justified it as *"I believe in STEM education because it will enable students to solve the problems they encounter in daily life, design projects, develop their cognitive development and develop their imaginations."*. There was no pre-service teacher who used the statement that "*STEM education contributes to 21st-century skills*" before theoretical knowledge. Seven pre-service teachers used the term 21st-century skills after the theoretical knowledge and five after the application. The fact that the number of participant pre-service teachers was 66 and none of them used the expression at the beginning of the research made us think that pre-service teachers did not associate 21st-century skills with STEM until the theoretical knowledge.

According to pre-service teachers before theoretical knowledge, the skills that STEM education leads to change; Collaboration (87%), designing (75%) and innovation (31%) skills. After the theoretical knowledge, according to the pre-service teachers, the skills that STEM education leads to change; Problem-solving (45%), creativity (18%), innovation (16%), entrepreneurship (13%), critical thinking (6%). After the application, according to the pre-service teachers, the skills that STEM education leads to change; Problem-solving (44%), innovation (32%), creativity (23%), cooperation (5%), entrepreneurship (7%), critical thinking (7%), communication (3%) skills.

In the pre-theoretical interviews, problem-solving skills were never mentioned by the pre-service teachers, but the ability to design was indicated with a percentage of 75%. It is thought that this difference.is because of the fact that the participant pre-service teachers participated in STEM education applications, in which models related to renewable energy were designed using educational Lego sets, and that they completed the projects in line with the instruction. PT20G10's opinion before the theoretical knowledge; *"Of course I embrace STEM education. STEM is more educational and useful. For example, Students will be able to design renewable energy themselves with Lego sets and learn by using their imaginations."* supports this idea. Problem-solving skills are at the forefront of the skills that pre-service teachers think STEM education will contribute to students after theoretical knowledge and practice. This may be due to the introduction of the Problem-based STEM model during theoretical knowledge, and the majority of the groups planning STEM activities for this strategy in practice. After the theoretical knowledge, PT50G4 explained the contributions of STEM to the student through the problem-based STEM model; *"With the problem-based STEM approach, students can find solutions to the problems they encounter in their daily life and do research."*. The post-application opinion of PT11G7 was *"The biggest shortcoming of the students is that they do not use the information they have learned in daily life. I intend to develop students with a problem-based STEM approach."* is in the form.

It is quite surprising that although cooperation skill is mentioned first in the list of skills changed by STEM education before the theoretical knowledge, it is not emphasized after the theoretical knowledge and is mentioned by very few pre-service teachers after the application. The pre-service teachers completed their activities by using instructions in the STEM study they participated in before the research. Knowing the product that will be formed in the directive projects at the beginning may have made the cooperation easier. In this study, pre-service teachers worked with the group to create their own projects like students. Pre-service teachers may have had difficulty collaborating in completing the open-ended STEM activity that required them to come together on a common point.

Both theoretical knowledge and post-practice pre-service teachers stated that STEM education will cause a change in students' creativity and innovation skills. Similarly, it is believed by pre-service teachers that entrepreneurship and critical thinking skills will contribute. After theoretical knowledge PT59G3; "*I believe in STEM education because STEM brings critical thinking, creativity, problem-solving and entrepreneurship in individuals."* she stated.

The second category created under the theme of contribution to students is the cognitive change category. Pre-service teachers expressed their opinions on cognitive change with high percentages before the theoretical knowledge. They stated that there would be an increase in students' knowledge of each discipline that makes up STEM. At the beginning of the research, pre-service teachers stated that STEM education would increase students' technology knowledge (80%), engineering knowledge (78%), science (78%) and mathematics knowledge (78%).

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However, this high percentage of consensus has not been seen after theoretical knowledge and application. The percentage of pre-service teachers who state that STEM will increase their technology knowledge is as low as 6% after theoretical knowledge and 5% after practice. While the opinion that there will be an increase in engineering knowledge was not encountered after the theoretical knowledge, it was expressed with a rate of 9% after the application. There was no pre-service teacher who expressed the opinion that there would be an increase in knowledge in science and mathematics disciplines after the theoretical knowledge and application. These findings showed that 14 weeks of interactive STEM education made a significant change in the views of pre-service teachers. Pre-service teachers initially interpreted STEM more superficially. *"Since it is mentioned in the name of science, technology, engineering and mathematics disciplines, there will be an increase in knowledge in these fields."* interpreted as. However, the theoretical and practical training provided has led to a change in this way of thinking. Pre-service teachers stated that STEM education provided students with an interdisciplinary perspective; after theoretical knowledge (33%) and after practice (28%). Relatedly, the percentage of opinions that STEM education will increase students' success and increase their knowledge is before the theoretical knowledge (48%), after the theoretical knowledge (24%) and after the application (7%). Opinions on the permanence of the knowledge; It is a decreasing percentage at the beginning of the study (78%), in the middle (10%), and at the end (5%). While pre-service teachers thought of STEM education as a miraculous approach to cognitive development at the beginning of the research, they did not think in the same way after the application phase, which helped them think like a student and formed more cautious statements. For example, PT48G7's opinion on STEM at the beginning of the research; *"I would ensure that STEM education is implemented in every school. In this way, the next generation would be more knowledgeable and cultured, while the knowledge given by heart is forgotten over time, the knowledge learned with STEM becomes permanent."* is in the form. If we look at the view of PT48G7 after the theoretical knowledge, a more cautious point of view is realized; "*STEM education is an application that will be useful in school. It will enable students to transfer knowledge. Time is needed for our country, as it is just beginning to settle down."* The opinion of PT48G7 after the practical training is; *"STEM can contribute to the development of many aspects of students such as conceptual learning skills and 21st-century skills. It can help students to look at the subject from all angles, not just take the knowledge, but question and research it."*

Four codes were determined under the theme of contribution to society. These codes are 1. raising individuals who are compatible with the developing world, 2. meeting the needs of qualified and productive people, 3. raising individuals who are aware of daily life problems, and 4. affecting the career choice of students. There was no pre-service teacher who expressed an opinion on each of the four code headings before the research. The percentage of pre-service teachers who gave their opinions on the topics after the theoretical knowledge decreased after the application. It is believed that this is due to the fact that developed country STEM goals are given during the theoretical knowledge. The decrease after the implementation may be that they think that it will not be so easy to reach the said goals. Percentages of pre-service teachers' opinions after theoretical knowledge; raising individuals who are compatible with the developing world (27%), meeting the needs of qualified and productive people (36%), raising individuals who are aware of daily life problems (21%), and affecting the career choice of students (12%). Percentages of pre-service teachers' opinions after the application; raising individuals who are compatible with the developing world (no opinion), meeting the need for qualified and productive people (13%), raising individuals who are aware of daily life problems (19%), and affecting the career choice of students (1%). A few examples from the views of pre-service teachers are as follows. After the theoretical knowledge PT5G7; *"STEM will benefit not only education but also many other fields, both in Turkey and in the world, and will be a pioneer in the development of societies. With the combination of more than one discipline, a much better product will emerge and there will be well-trained and qualified individuals in every field."* she said. The opinion of PT8G5 is; *"He knows how to use his knowledge skills in the tasks that a person has to do in his daily life and in the problems that need to be solved. In the simplest way, a child can make a fountain to be built in the garden of their house together with his father".*

In the interviews at the end of the research, the pre-service teachers were asked "whether there were any difficulties in the implementation phase" and, if so, "what happened". In addition, how should STEM education be given to teacher candidates? The question has been posed. Pre-service teachers stated that STEM discipline integration is difficult (34%) and they had difficulties in performing STEM activities due to insufficient engineering education (50%). During the application, pre-service teachers wanted to use sensor sets in their projects and they wanted to use "Arduino", one of the programming platforms suitable for this and is thought economical and the programming language is easy. However, they stated that they had difficulties in this adventure and because they did not know coding (50%), they received support from their friends studying in the software engineering

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department. They stated that STEM education should be given as a course during their undergraduate education (67%). Before the training, it was stated that in order for the pre-service teachers to adopt STEM education, their contributions should be explained (11%) and that they should be associated with daily life (7%).

For PT24G2, the part where she had a hard time was; "*We used Arduino in our project, and it was not something I had seen before in my life. It was difficult to work with unfamiliar materials and it was a difficult process in the coding part"*. Regarding providing STEM education to pre-service teachers, *"They must have a readiness before coming to university. STEM should be applied in other education levels, albeit to a lesser extent. Starting from the first grade, the pre-service teacher should see engineering in addition to the field courses, know technology well, and STEM applied courses should be given".* For PT27G8; *"We had a hard time integrating engineering and technology. We got help from our friends studying in the software engineering department".* The opinion of PT61G7 is; *"During this process, I had the chance to do inquiry. I saw that teachers defended the STEM understanding by doing simple repetitive activities that they saw on the internet. They open various courses about STEM that have no theoretical foundation, but I think they are of no use to students. The main thing is to make the student think about STEM. Therefore, the contributions of STEM should be explained to pre-service teachers, and they should be adopted."*

In all three stages, the pre-service science teachers were asked which STEM learning and teaching models they preferred to use. At the beginning of the research, it was understood that pre-service teachers did not adopt a certain STEM learning and teaching model. They answered the question by giving examples from the activities they did using the Lego sets they participated in before the research. I use Lego sets if available at my school (25%), I build a wind/solar car (42%); I can't do without STEM materials (18%), I have no STEM understanding (15%). It was thought that the pre-service teachers could not make sense of the question because STEM theory knowledge was not given in the training they attended before the research. After the theoretical training, the answers of the pre-service teachers were distributed as follows: Four different models were specified: Problem-based STEM (43%), 5E integrated STEM (45%), project-based STEM (13%), and design-based STEM (9%). Seven pre-service teachers (PT8G5, PT17G9, PT27G8, PT31G5, PT39G5, PT41G9, PT52G4) stated more than one option. During the theoretical knowledge, learning and teaching models used in the literature were introduced, and access to the sources with sample applications was provided. The fact that pre-service teachers stated a STEM learning model compared to the beginning of the study showed that it is important to give STEM theoretical knowledge. In the interviews made after the STEM applications, the most preferred learning model was Problem-based STEM (63%). Project-based STEM (23%) ranked second. Eight pre-service teachers stated that a single STEM learning and teaching method is not correct and emphasized that different models should be used depending on the situation (ÖA9G10, PT21G10, PT24G2, PT28G6, PT43G10, PT46G9, PT56G3, PT58G2). One pre-service teacher stated the design-based STEM (PT29G2), 5E integrated STEM (PT52G4), and Science-based STEM (PT4G5) models as the adopted model. During the implementation process, pre-service teachers performed 11 group and one individual STEM activities (Table 1). Seven of these activities were prepared using the problem-based STEM, four of them using the project-based STEM, and one using the design-based STEM model. According to the data obtained, it can be said that the teacher candidates adopt the problem-based STEM model more. Examples of pre-service teachers' opinions;

The opinion of PT66G12, who worked individually during the implementation phase; *"I had prepared my application activity according to the project-based model. But problem-based thinking is actually better. It would be a priority for me to put more creative thinking towards life's problems and put it into practice in life."*

PT34G3*; "We need to analyze a certain problem situation and find various solutions in line with these problems, so I think problem-based STEM would be a better model."*

PT46G9's opinion; *"Our group work was oriented towards a problem-based STEM model. However, any STEM model that the person considers self-sufficient can be used. Model selection may vary depending on which teaching level it is used and for a better realization of the solution and subject. I think the problem-based STEM model is more advantageous because it leads to problems that exist in daily life."*

PT23G8; *"I adopt the project-based STEM model because new products must be obtained to make life easier."*

Discussion

In the study, pre-service science teachers were asked to define STEM at three different times in order to determine pre-service teachers' understanding of STEM and whether their understanding changed according to the training given in the process. The definitions of pre-service science teachers are gathered under seven codes under the headings of abbreviation of disciplines, integration of disciplines, combining of disciplines, coverage of disci-

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plines, problem-solving about daily life, linking of disciplines, and education without rote. In addition, there were five different definitions at the beginning and two different definitions in the middle of the study by pre-service teachers. Eight conceptualized integrated STEM education models were proposed in the study conducted by Ring et al. (2017). Three of these models, an abbreviation of disciplines, integration of disciplines, and problem-solving from daily life, are similar to the definitions of pre-service teachers in this study. Dare et al. (2021) found in their research that teachers have a STEM education perspective in which real-world problems are used after participating in STEM-focused professional development and performing integrated STEM lessons in their classrooms. Sarioglu et al. (2022), the definitions of interdisciplinary approach and understanding real life problems came to the fore in the study they conducted with teachers who had participated in various STEM trainings before. It showed parallelism with the definition of "problem-solving from daily life" obtained in this study. In this research, STEM was expressed by pre-service teachers as "solving real-world problems" after theoretical knowledge and application. STEM definition accepted by more pre-service teachers at the end of the research; definitions of "combing of disciplines " and " integration of disciplines". At the end of the research, pre-service teachers moved away from the non-explanatory definition of "the abbreviation of science, technology, engineering and mathematics disciplines". Pre-service science teachers changed their definitions of STEM during the theoretical and applied education process they attended. However, there is no single definition that all pre-service teachers agree on. The differences in the definitions of the pre-service teachers in the same group showed that STEM was not interpreted the same by the pre-service teachers. According to the studies (Bybee, 2013; English, 2016; Johnson, 2012; Paz et al., 2022) showing that there is no single definition of STEM, this situation was not surprising. However, the point to be discussed is that despite participating in the same theoretical and practical training, STEM education, which is perceived differently, is that the students of pre-service teachers who will do STEM applications with their own students in the future will encounter completely different applications under the name of STEM. Although conceptualizing a common STEM model is difficult, a clearer environment can be created (Breiner et al., 2012).

Pre-service teachers were asked whether they felt competent in STEM education, and the answers were grouped under three themes: being fully competent in STEM education, partially competent in STEM education, and not being competent in STEM education. It was understood that the majority of pre-service teachers think of themselves as partially competent. It is understood that the percentage of teacher candidates who find themselves competent increased after the theoretical knowledge but decreased again after the application. In parallel with this research result, Bartels and Rupe (2019) found that pre-service teachers' understanding of STEM did not increase even after they planned and implemented STEM lessons. This may be because they realize that the points that seem feasible with theoretical education are not as expected in applied education. Teachers' participation in STEM teaching can be supported by improving their self-efficacy in STEM practices (Dong et al.,2019; Shahali et al., 2015). It is thought that pre-service teachers will be more conscious while guiding their students in the future with the proliferation of STEM applications in which they participate as students. Many studies with teachers and pre-service teachers stated that they needed courses and in-service training to improve themselves in the field of STEM (Aydeniz, 2017; Yıldırım et al., 2022; Yıldız, 2023). The decrease in the number of pre-service teachers who do not find themselves competent after the theoretical knowledge has shown that the training to be given, even at the theoretical level, will contribute to the STEM competence of the pre-service teachers. This result is in line with the studies that the courses or trainings provided contribute to the STEM competencies of teachers (Arslanhan & İnaltekin, 2020; Dong et al., 2019).

In the research study, the understanding of the pre-service teacher, who stated that he was far from STEM education because it was a foreign-sourced model, was found to be very important. Çepni (2017) stated that some mistakes were made in the process of spreading STEM education in Turkey, such as giving STEM certificates with a few-day courses, calling hobby courses STEM, and assuming that STEM can only be done with expensive and robotic sets. Although there are some studies carried out in education faculties programs, the absence of STEM courses at the undergraduate level requires pre-service teachers to improve themselves with their personal efforts at this point and to find their own truths in information pollution.

Pre-service teachers stated that they believed in STEM education and explained their possible contributions. The fact that pre-service teachers do not actively teach and have never tested STEM with students is the inference of the possible contributions they have stated as a result of their experiences in their own education processes. The answers of the pre-service teachers regarding the possible contributions of STEM education were examined under two themes as contribution to the student and contribution to the society. According to pre-service teachers, STEM education causes positive changes in students' skills and cognitive and affective development. There are many studies about STEM education, that confirm the inferences of pre-service teachers, contribute to the cogni-

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tive development of students (Fan & Yu, 2017; Wendell & Rogers 2013), contribute to their affective development (Bakirci et al., 2022; Keçeci et al., 2017), contribute to students' skills (Sahin & Top, 2015; Zengin et al., 2022), studies that affect career choices (Chachashvili-Bolotin et al., 2016; Tanenbaum, 2016). In this research, problem-solving and creativity skills were stated as the leading skills that STEM education contributed by the pre-service teachers. Interestingly, collaboration and design skills were stated by the majority of pre-service teachers before the research, but the pre-service teachers who advocated different models had problems in cooperation while working on a project by meeting on a common point. The collaboration skill was emphasized by very few pre-service teachers at the end of the process. Pre-service teachers who advocated different models had problems in cooperation in this research, where they met on a common point and completed a project. Collaboration may have been easy for pre-service teachers in STEM applications, which they designed based on the instructions they participated in before the research. In this case, it can be concluded that the method followed in STEM applications and the skills affected at the end of the process will vary.

Pre-service teachers' understanding about the contribution of STEM education to society is raising individuals who are compatible with the developing world, meeting the needs of qualified and productive people, raising individuals who are aware of daily life problems and making connections, and affecting the career choice of students. These results are consistent with the targeted outcomes in STEM reports (MNE, 2016; NRC, 2012; TUSIAD, 2014). There were no pre-service teachers who expressed similar views before the research, it increased after the theoretical knowledge and decreased after the application. It is believed that this is due to the fact that developed country STEM goals are given during the theoretical knowledge. The decrease after the implementation may be that they think that it will not be so easy to reach the said goals.

In the application part of the research, pre-service teachers prepared a STEM activity that they could apply with their students in the future, and a lesson plan on how to implement the activity, according to a STEM model they chose with their group friends. The pre-service teachers stated their science, technology, engineering and mathematics achievements in their activity plans and presented to their friends how they integrated the disciplines and which STEM approach they adopted. Pre-service teachers had a very difficult time in STEM discipline integration. Vasquez et al. (2013) stated that integration can be used at various levels such as transdisciplinary, interdisciplinary, multidisciplinary and disciplinary. The difficulty of pre-service teachers may be that they cannot choose from this diversity. Dare et al. (2019) stated that teachers have a limited understanding of what STEM is and what it means for their teaching, despite all the guidance. Alan et al. (2019), in their study that aimed to support pre-service science teachers' integrated teaching knowledge through STEM applications, found that pre-service teachers believed in the necessity of STEM education, but thought that discipline integration was not easy. Pre-service teachers stated that they had the most difficulties in the implementation process due to the inadequacy of their engineering education. Except for two groups, other groups wanted to use sensor sets in their projects and wanted to use "Arduino", one of the programming platforms suitable for this. However, they stated that they received support from their friends studying in the software engineering department because they did not know coding. It has been stated in many studies that pre-service teachers think that they are inadequate in engineering and that they do not trust themselves (Akgündüz et al., 2015; Avsec & Sajdera, 2019; Aydeniz & Bilican, 2017; Aydeniz & Cakmakci, 2017; Blackley & Howell, 2015). Pre-service science teachers stated that engineering and STEM education should be given as a course in undergraduate education, especially coding learning is necessary. Aydeniz (2017) stated that students studying in science and mathematics departments should take at least two practice-oriented coding courses. When it comes to engineering content integration, it is thought that software engineering comes to the fore because most of the current technologies require coding and the spread of STEM education in Turkey is mostly through robotic sets.

Pre-service science teachers adopted the problem-based STEM model among STEM learning and teaching models and preferred to use it. Pre-service teachers emphasized problem-solving in their STEM definitions and contributions questions. It was an expected result that the STEM learning model they chose was a problem-based model. 5E integrated STEM, project-based STEM, design-based STEM, and science-based STEM models were also shared by pre-service teachers. Yıldırım (2018) stated STEM models as project-based learning, inquiry-based learning and problem-based learning models in his research. In this research, project-based STEM was preferred in the second place. Eight pre-service teachers stated that a single STEM learning and teaching method is not correct and emphasized that different models should be used depending on the situation. There is no single model in STEM education with which consensus has been established (Dare et al., 2019; Sarıoğlu et al., 2022; Selvi & Yıldırım, 2017). Therefore, the important thing is that teacher candidates know the models, have a good command of STEM education and can apply any model they want.

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Conclusions and Implications

In the study, in which STEM education was determined as a phenomenon and how the pre-service science teachers adopted it, what the understanding of pre-service teachers' STEM education was, whether they thought of themselves as sufficient, and their predisposition to STEM teaching and learning models, valuable results were obtained. The results help us to look at STEM education from the perspective of pre-service science teachers. There is no single definition that pre-service science teachers agree on. Despite their collaborative work during the implementation phase, the pre-service teachers did not unite in a common definition, and each pre-service teacher expressed their own definition of STEM. Most of the pre-service science teachers defined STEM as "the abbreviation of disciplines" without going into details at the beginning of the research, but they moved away from this definition after theoretical knowledge and practical training. STEM definitions prominent by pre-service teachers are; "combining of disciplines", "integration of disciplines" and "solving daily life problems".

Today, when we are about to complete the first quarter of the 21st century, it is very important to increase the competencies of our teachers who will raise the generations that will deal with much bigger problems in the future. The number of pre-service science teachers who did not consider themselves competent at the beginning of the study decreased after the theoretical and practical training. The number of science teachers who consider themselves competent has increased. However, some of the pre-service teachers who felt fully competent after the application defined themselves as moderately competent. Although the majority of pre-service teachers participated in theoretical and practical training, they defined themselves as intermediate level competency in STEM education. The trainings provided contributed to the STEM competencies of pre-service science teachers. As stated by the pre-service teachers, the self-confidence of the pre-service teachers can be increased by providing the trainings throughout their undergraduate education.

Participating pre-service science teachers believe in STEM education. They explained the reason for their belief through the possible contributions they would make to the students. According to pre-service teachers, STEM education contributes to both students and society. Pre-service science teachers had the most difficulty in disciplinary integration during the STEM theory and practice education process they attended. The pre-service teachers stated that their engineering knowledge was lacking and stated that they should especially receive coding training. The majority of pre-service science teachers preferred to use the problem-based learning model among STEM learning and teaching models. Some pre-service teachers stated that a single model would not be correct and that different models should be used depending on the situation.

Unlike the studies examining the understanding of pre-service teachers about STEM education, in this study, it was tried to determine the changes in pre-service teachers' understanding of STEM during the STEM education process.

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SCIENCE TEACHERS' APPROACH TO CONTEMPORARY ASSESSMENT WITH A READING LITERACY EMPHASIS

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Abstract. *In a sample of 1215 teachers, this study examined the readiness of science educators for assessment in the rapidly evolving landscape of artificial intelligence in education. Participants responded to an online questionnaire during the emergency remote teaching phase, offering insights into the frequency and nature of assessment methods utilized. The research draws a connection between assessment techniques during remote teaching and the emergence of AI in education. The results show that the selected assessment methods vary across teachers, with some specific differences observed in the assessment practices of science teachers. The study underscores the critical role of reading literacy in enhancing student engagement in contemporary learning environments. Moreover, the findings suggest that continuous professional development significantly improves the readiness of (science) teachers for AI-enhanced assessment. Drawing from these insights, recommendations for subsequent research are delineated.*
Keywords: *artificial intelligence, assessment, reading literacy, science teachers, teacher training*

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Introduction

The OECD (2022) defines AI systems as machine-based entities capable of making predictions, recommendations, or decisions influencing real or virtual environments, aligned with human-defined objectives. Many educators and professionals remain unaware that national AI education policies were established even before ChatGPT's emergence, a milestone in AI's educational integration. The OECD began addressing this as early as 2021 (Galingo et al., 2021), summarizing various national strategies. Notably, AI educational guidelines, such as "Is education losing the race with technology" (OECD, 2023) and "OECD digital education outlook" (OECD, 2021), were established before ChatGPT's advent. The European Commission has also contributed with publications like "Ethical Guidelines on the use of artificial intelligence (AI) and data in teaching and learning for Educators" (European Commission, 2022) and "White paper on artificial intelligence – a European approach to excellence and trust" (European Commission, 2020). However, until Open AI popularized ChatGPT in November 2022, these documents seemed futuristic. Now, they hold immediate relevance. Natural language processing tools, exemplified by ChatGPT, have revolutionized education. This AI-driven model assists in diverse tasks, from coding to essay writing. As a result, the educational sector is undergoing significant transformation. The predictions of Seldon and Abidoye (2018) in "The Fourth Education Revolution" have rapidly materialized. The sudden emergence of such tools found many educators unprepared, leading to polarized views on AI's role in education. Regardless of perspective, AI's ubiquity necessitates strategic adaptation. Some nations have even implemented regulations or outright bans on tools like ChatGPT, emphasizing the need for ethical engagement with AI in education (Bhati, 2023; McCallum, 2023; Yang, 2023). Cotton et al. (2023) highlight the dual nature of AI in education, presenting both challenges and opportunities. Educational assessment serves multifaceted purposes, with its nature diverging based on the chosen method. Criteria such as construct validity, reliability, desired impact, and resource optimization

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are essential for evaluating assessment techniques. Teacher assessment remains central to these criteria (Harlen, 2007). Conventional assessment methods, primarily paper-based, are familiar to educators (Montgomery, 2002), however, these methods are characterized by rigid question formats, offer a limited snapshot of an individual's capabilities often sidelining multifaced learning perspectives (Frey & Schmitt, 2010), and do not cater to students' unique knowledge, skills, and experiences and evaluate competencies typically beyond computerization (Swiecki et al., 2022). While teachers have incorporated technology to support conventional assessment practices (Grion et al., 2018) and have adapted their pedagogical and evaluative strategies during exigencies (Legvart et al., 2022; Turan-Güntepe et al., 2023), AI's advent in grading introduces novel dimension. AI's inherent nuances necessitate educators' cognizance during evaluation, transcending mere performance measurement. Educators must contemplate assessment's overarching role and objective, as it significantly influences both teachers' and students' value perceptions. Such reflection enables judicious student evaluation, catering to the varied expectations of stakeholders through the assessment trajectory and its outcomes (Dunn et al., 2004, p. 15). Yet, educators must remain vigilant of A's constraints, exemplified by ChatGPT, which is characterized by post-September 2021 knowledge gaps, misinformation, comprehension lapses, and hallucinations, potentially generating spurious data. Such scenarios, exacerbated by a failure to align with children's development nuances, risk jeopardizing their well-being. This challenge becomes pronounced with AI not explicitly designed for educational purposes, especially concerning younger students. This predicament starkly contrasts with the child-centric AI principles delineated by UNESCO (Miao et al., 2020, p. 4), which has underscored child protection from AI's adverse impacts, child agency in AI system shaping, and the judicious harnessing of AI's potential benefits.

While teachers may not have direct experience with assessment in the emerging landscape of artificial intelligence in education, parallels can be drawn with their experiences during remote teaching. The transition to remote teaching, necessitated by global circumstances, required educators to swiftly adapt and integrate technology into their assessment practices. This rapid shift, much like the introduction of AI in education, presented both challenges and opportunities for educators. Experiences from the period of emergency remote teaching have indicated that while traditional assessment methods possess inherent advantages, they may not fully capture the breadth and depth of learning and teaching in technologically advanced environments. The integration of AI into assessment necessitates a re-evaluation of existing practices. The parallel, link, and interplay between distance learning and artificial intelligence are explored in numerous studies (e.g., Aljarrah et al., 2021; Tang et al., 2023). These developments call for modifications in teaching methodologies, assessment practices, and the incorporation of digital tools, emphasizing the critical role of digital literacy competencies. The shift to remote teaching provides insight into teachers' adaptability and potential readiness for the integration of AI-driven assessment methods. Recent research further supports the perspective. Kim and Kim (2022) highlighted the significance of teachers' perceptions of AI-enhanced tools in STEM education, suggesting that successful AI integration is influenced by teachers' attitudes and prior experiences. Kerneža and Zemljak (2023) posited that teachers have preconceptions about future technologies, such as humanoid robots and AI, that influence their perceptions of these technologies. Salas-Pilco, Xiao, and Hu (2022) examined the relationship between AI and learning analytics in teacher education, emphasizing the importance of understanding teachers' digital competence and their views on AI's role in teaching. Assessment in remote settings frequently involves the utilization of digital tools, many of which are intrinsically linked to artificial intelligence. Understanding how teachers employ and adapt to remote assessment techniques can serve as an indicator of their readiness and capability to integrate AI into evaluation processes. Furthermore, their receptiveness to adopting new technologies within the context of remote assessment may reflect a broader preparedness for innovations, such as the incorporation of artificial intelligence in educational practices. Given these insights, it is justified to generalize teachers' feedback on distance education to the broader context of AI-driven assessment. The shared challenges and opportunities in both areas, informed by recent research findings, offer a comprehensive understanding of teachers' preparedness for the evolving landscape of AI in education.

Research Problem

The educational landscape is dynamically evolving in real time. The OECD (2018) highlighted the unparalleled advancements in science and technology, especially in biotechnology and AI, as pressing challenges for the future of education. Among the multifaced dimensions of AI in education, the rise of ChatGPT, alongside other current and forthcoming generative pre-trained transformers and large-scale language models, draws particular attention

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to the assessment and unique features that advanced technologies bring. Following initial restrictions on ChatGPT in specific countries, there is a growing consensus that chatbots should not be banned, but rather that students should be taught how to use them responsibly (Crawford et al., 2023; Gimpel et al., 2023). The discourse underscores the pillars of integrity, ethics, and personal responsibility, emphasizing that individuals are responsible for the quality of their work (Rudolph et al., 2023). There's also a call for discerning utilization and understanding the inherent boundaries of non-human text generators, with a spotlight on the intrinsic worth of human composition (Anson & Straume, 2022; D'Agostino, 2022; Fyfe, 2022), which remains a cornerstone of intellectual growth (Mills, 2023). Currently, there's a push for assessment methodologies that prioritize oral presentations, self-reflection, performance-based assessment, and peer assessment, all underpinned by collaborative work (Gimpel et al., 2023; Rudolph et al., 2023). The incorporation of mentorship and coaching, which segment learning into smaller pieces and provide more feedback, is perceived as beneficial (Gimpel et al., 2023). Indeed, this pivotal moment may mark a paradigm shift from conventional pedagogical approaches towards not just innovative, but deeply transformative instructional strategies.

Research Focus

In the realm of pedagogical advancements, the deployment of intricate, non-traditional assessment tools becomes imperative. Specifically, within the curriculum framework, science teachers ought to plan assignments that encourage students to think critically (Rüütmann, 2019). Furthermore, teachers should review assignments and assessments in their courses (Teaching in the AI era, 2023). The initial stride toward this objective was catalyzed by emergency remote teaching (Khan et al., 2021). The next phase should include the integration of new AI technologies. The subsequent phase should encompass the seamless integration of emergent AI technologies. Contrary to the procedural aspects of AI-driven assessment, such as automated grading as described by Gardner et al., (2021), the primary research emphasis pivots towards the evaluation of knowledge, both facilitated by and rooted in AI. The deployment of AI in this context can manifest in concealed, explicit, or intentional forms, contingent upon the educator's strategic choices. The present study draws from teacher feedback collated at the end of the emergency remote teaching phase, wherein they elucidated the assessment modalities employed during remote instruction. Distance remote teaching has indeed opened the door to unconventional forms of learning and assessment, such as scalability, research innovation, flexible learning, diversity, adaptation of assessment methods, and potential for innovation (Gurajena et al., 2021). The primary research focus was to examine teachers' readiness to embrace novel assessment methods resulting from the application of AI. It seeks to understand the challenges teachers may encounter when evaluating novel environments, including those related to reliability, fairness, and objectivity of assessment using AI.

Research Aim and Research Questions

The research aim was to explore the preparedness of science teachers for assessment in the age of AI, considering the challenges and opportunities presented by the widespread accessibility of AI technologies in education. One of the major goals of this study was to understand the specific factors contributing to teachers' readiness or their lack thereof. Furthermore, the study had an objective to discern potential differences or similarities in the preparedness of science teachers compared to teachers in other subject areas. Through these detailed objectives, the overarching aim was to offer insights into teachers' readiness for AI-based assessments, thereby guiding educational practices and policies in adapting to the evolving landscape of technology in education. The following research questions were formulated:

RQ1: Are teachers ready for assessment in the era of widespread accessibility of AI in education?

RQ2: Are there differences between science teachers and teachers of other subjects in terms of assessment in the era of widespread accessibility of AI in education?

RQ3: Is assessment in the era of broad accessibility of AI in education based on novel models that require higher levels of reading literacy?

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Research Methodology

General Background

In the contemporary educational landscape, the integration of artificial intelligence (AI) is reshaping learning and teaching paradigms. The broader context of this transformation underscores the importance of adapting assessment strategies to these technologically advanced environments. A review of existing literature reveals a consensus on the need for novel approaches to learning, teaching, and assessment that align with 21st-century skills. However, a notable gap emerges when juxtaposing this consensus with the current state of teacher preparedness. Many educators, despite the wealth of research advocating for change, remain inadequately equipped to navigate the intricacies of assessment in an AI-augmented setting. This disparity between the recognized educational imperatives and the actual capabilities of teachers is further accentuated with the rapid proliferation of AI in educational settings. The urgency of this matter becomes even more pronounced when considering the responses from educators during the emergency remote teaching phase. During this period, the transformative potential of AI, rather than being an integral part of the educational process, was often perceived as a distant, futuristic concept. The study draws on data collected during the period of emergency remote teaching, presenting a unique context for understanding how teachers adapt and respond to technological shifts. This specific timeframe allows us to comprehend assessment practices under exceptional circumstances, which can serve as a foundation for understanding teacher readiness and needs in an era of rapid technological advancement, such as the integration of AI. The intention is to offer insights that can shape practices, policies, and further research, ensuring that the educational community can harness the full benefits of AI while addressing its challenges.

Sample

The survey is based on a questionnaire completed by 1215 teachers from primary and secondary schools in Slovenia. The sample size of 1215 was determined based on a power analysis to ensure adequate statistical power for detecting meaningful differences and associations in the data. A power analysis was conducted to determine the appropriate sample size. The power analysis was performed considering an anticipated effect size of $d = .5$ (Cohen, 1988). The standard deviation of responses, obtained from a pilot study, was also considered and found to be 1.2. The calculation was carried out using the SPSS software, an aim was set to achieve a test power of .85 to reliably detect statistically significant effects, should they exist. The Type I error rate was set at .05. Based on these parameters, the power analysis indicated that a sample of at least 1050 teachers was required to reliably detect the anticipated effects. Based on this analysis, a decision was made to obtain a sample of 1215 teachers, which exceeds the minimum required sample size determined by the power analysis. Teachers were selected from different regions, including urban and rural areas, to ensure a diverse and representative sample. This stratified sampling approach aimed to capture the varied experiences and perspectives of teachers from different geographical and demographic backgrounds, allowing more robust generalization of the results. Although a non-probabilistic method was employed, teachers were randomly selected based on their accessibility and willingness to participate. This approach was chosen to maximize participation while ensuring a diverse range of respondents. The breakdown of participating teachers is as follows: 182 primary school teachers (teaching all school subjects), 268 social science teachers, 227 science teachers, and 246 vocational teachers. In terms of teaching experience, most of the participating teachers had more than 20 years of experience (50.04 %), followed by 15.97 % of teachers with 15-20 years of experience, 13.00 % of teachers with 5 years of experience or less, 12.02 % of teachers who have been teaching for 10-15 years, and 8.97 % of teachers who reported 5-10 years of experience. The varied experience levels further enhance the representativeness of the sample, capturing insights from both seasoned educators and those newer to the profession.

Instrument and Procedures

The research was conducted at the end of the 2021/2022 school year, coinciding with the conclusion of emergency remote teaching. The primary objective was to gather insights into the pedagogical strategies employed by teachers during the remote teaching phase, to develop pedagogical recommendations and guidelines in case the need for remote teaching arises again. The initial questionnaire consisted of 18 items representing dependent

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variables and 5 items representing independent variables. To ensure the instrument's robustness, a validation study was initiated to scrutinize the questionnaire's structure and affirm its construct validity. The study aimed to validate the measures used to assess teachers' assessment in the time of emergency remote teaching. The questions were based on teachers' experiences reported in various courses they attended during the pandemic. Participants included 2 teachers from the first triennium of primary school, 2 teachers from the second triennium of primary school, 2 teachers from the third triennium of primary school, 2 teachers from a vocational high school, and 2 teachers from a grammar school. Based on the results, the questionnaire was found acceptable.

The final questionnaire for teachers was designed and published on the online platform 1ka.si. It was distributed through various forums and websites to teachers who matched the predetermined sample. The questionnaire was also distributed among teachers with a request to share the link with their colleagues. For the original purpose of drawing conclusions about remote teaching, half of the results were used, except for the question about assessment during remote teaching. However, with the emergence of AI and its broader impact on education, the question of assessment in new learning environments and under new instructional and teaching conditions has become relevant again. To understand teachers' readiness for unconventional assessment methods, answers to questions posed in these new learning environments can provide valuable insights. Due to teachers' limited awareness of AI and the practical benefits it can have for them, as shown by a survey conducted in Estonia, which ranks first among the 27 European countries in the Index of Readiness for Digital Lifelong Learning (IRDLL) (Chounta et al., 2022), a new questionnaire was deliberately not designed, as the original one also covers new teaching methods, even in the age of AI (Zimmerman, 2018). This decision was made because a similar question related to the environments with which teachers are already familiar after the COVID crisis provides sufficiently clear results and answers regarding teachers' opinions about unconventional assessment methods in the classroom. These responses are later interpreted in the context of the emerging construct of AI. The responses to the questions asked in these new learning environments may help to understand teachers' readiness for unconventional assessment methods. The surveyed question consisted of five items that provided data on assessment approaches during emergency remote teaching. Teachers answered these questions on a 4-point Likert scale (1 – never, 2 – rarely, 3 – often, 4 – mostly). They rated the frequency of assessment through videoconferencing, quizzes and tasks in online classrooms, written assessments, evaluation of seminar papers, and assessment of authentic assignments, video products, and projects during emergency remote teaching. Finally, teachers also responded to a demographic question, from which the information about their primary educational domain was obtained. The options for selection were primary school teacher, social sciences teacher, natural sciences teacher, and vocational subject teacher.

The Cronbach's alpha coefficient, with a value of .771, showed reliable internal consistency (Nunnally, 1978). The commonality data indicated the extent to which each variable contributed to the extracted factors, and all variables had appropriate values for further interpretation (oral assessment using video conferencing = .568; quizzes and tasks in online classrooms = .523; written assessment = .567; evaluation of seminar papers = .553; assessment of authentic assignments, video products, and projects = .797).

Ethical Procedures

All measurements and interventions were conducted in accordance with applicable ethical guidelines and were voluntary for teachers who chose to participate in the study. Prior to their involvement, teachers provided informed consent, granting permission for the utilization of their data for analytical purposes and subsequent publication of findings. All information collected was processed and stored in accordance with applicable data protection regulations. A special emphasis was placed on safeguarding the privacy and ensuring the anonymity of the participating educators. To this end, all collected materials maintained teacher anonymity through the deployment of encrypted identification codes, eliminating any possibility of tracing back to individual identities. Throughout the entirety of the research process, the highest ethical standards were rigorously upheld. The rights, dignity, and overall well-being of all participants were consistently prioritized and respected.

Data Analysis

Reliability analysis was conducted to examine the questionnaire structure. To measure the internal consistency of the questionnaire, Cronbach's alpha coefficient was employed. The Kruskal-Wallis analysis for independent samples was performed to test for statistically significant differences among groups of teachers based on their

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primary educational domain. In the context of the Kruskal-Wallis test, the magnitude of the effect of the observed differences was calculated. Furthermore, a post hoc analysis using Dunn's test was conducted to explore specific differences between groups of teachers. Descriptive statistics were employed to obtain basic information on mean scores, standard deviations, and ranges within each assessment category. The data were analyzed using IBM SPSS software.

Research Results

In accordance with the research conducted, the general results regarding the forms of assessment during emergency remote teaching are presented, based on how frequently they were chosen by the teachers.

Table 1
Frequency of Using Different Assessment Methods during Emergency Remote Teaching

Assessment Method	*N*	*M*	*SD*
Oral assessment using video conferencing	1215	2.39	1.176
Quizzes, tasks in online classrooms	1215	2.07	1.038
Written assessment	1215	1.54	.869
Assessment of seminar papers	1215	1.95	1.012
Assessment of authentic tasks, video productions, projects	1215	2.29	1.121

The results presented (Table 1) show that during emergency remote teaching, teachers predominantly assessed students' knowledge through oral assessment via video conferencing ($M = 2.39$). The average of all responses given is also found for the frequency of assessment through authentic tasks, video productions, and projects ($M = 2.29$). Less frequently, teachers chose quizzes and tasks in online classes ($M = 2.07$) and assessment of seminar papers ($M = 1.95$) less frequently, while they least frequently chose to assess student knowledge through written assessment ($M = 1.54$). The variable of written assessment showed the least variability in teachers' responses ($SD = .869$), indicating greater consensus among teachers regarding the choice of written assessment in distance learning. The greatest dispersion of results was found for oral assessment using video conferencing ($SD = 1.176$) and assessment of authentic tasks, video productions, and projects ($SD = 1.121$), suggesting that teachers vary in how well prepared they are to assess in this way. However, the variance is still relatively small, suggesting some degree of consistency in assessment using the above methods. Slightly, but not significantly, different scores were observed for quizzes and tasks in online classrooms ($SD = 1.038$) and assessment of seminar papers ($SD = 1.012$), where the teachers' scores were somewhat more similar.

Table 2
Assessment Methods during Emergency Remote Teaching according to Their Primary Field of Teaching

	Primary school teacher		Social sciences teacher		Natural sciences teacher		Vocational subject teacher	
	N	*M*	*N*	*M*	*N*	*M*	*N*	*M*
Oral	182	412.94	368	521.75	418	462.07	247	445.43
Quizzes	182	425.81	368	438.42	418	510.22	247	507.21
Written	182	364.60	368	465.78	418	487.32	247	515.57
Seminar	182	295.25	368	472.69	418	465.79	247	591.93
Authentic	182	406.52	368	484.33	418	441.34	247	507.60

Note. *Oral* – Oral assessment using video conferencing. *Quizzes* – Quizzes, tasks in online classrooms. *Written* – Written assessment. *Seminar* – Assessment of seminar papers. *Authentic* – Assessment of authentic tasks, video productions, projects.

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The results presented in Table 2 show statistically significant differences in the choice of assessment methods among teachers based on their teaching area (H(3) = 23.249, p = .001, η^2 = .02). Video conferencing assessment was most frequently used by social science teachers (M = 521.75), which is consistent with their preference for interactive teaching methods and discussions with students. Science teachers (M = 462.07) and vocational subject teachers (M = 445.43), on the other hand, used it less frequently, possibly due to the practical nature of their subjects, which is more difficult to assess through videoconferencing. Primary school teachers (M = 412.94) were the least likely to use it, likely due to the challenges of providing appropriate technology and addressing the developmental needs of younger students. The small effect size (η^2 = 0.02) does not detract from the statistical significance of the differences found (p = .001). The teaching domain is only one of potentially many influencing factors, which means that further research is needed.

Based on the results of the Kruskal-Wallis test (H(3): 19.642, p = .001, η^2 = .02), significant differences were found between at least two groups of teachers in their use of quizzes and assessment tasks. Teachers of science subjects (M = 510.22) and teachers of vocational subjects (M = 507.21) most frequently assessed their students using quizzes and tasks, which could be attributed to the interactive and practical nature of their subjects that lend themselves these assessment methods. Social science teachers (M = 438.42) and primary school teachers (M = 425.81) used quizzes and tasks less frequently, which may be due to the emphasis on conceptual understanding in social science subjects and the use of alternative assessment methods for primary school students to gauge comprehensive understanding. Despite the small effect size (η^2 = 0.02), the statistical significance of the observed differences (p = .001) remains unchanged. The pedagogical domain is only one of many possible elements influencing these differences, highlighting the need for further research.

Statistically significant differences in the frequency of written assessment (H(3): 45.005, p = .001, η^2 = .04) were found between the different groups of teachers. Teachers of vocational subjects (M = 515.57) chose written assessment most frequently, probably because it is suitable for assessing skills and subject knowledge. Natural science teachers (M = 487.32) and social science teachers (M = 465.75) used written assessment less frequently because their subjects focus primarily on theoretical concepts that may be better assessed using other methods. Primary school teachers (M = 364.60) were least likely to use written assessment, possibly due to the challenges of developing writing and reading skills in younger students, leading them to choose more appropriate assessment approaches for their developmental stage. The observed effect size (η^2 = .04) means that although the differences are statistically significant, the variance in the frequency of writing assessments between the different teacher groups is only marginally explained by the instructional domain. This suggests that other factors may also play a significant role in teachers' choice of assessment method.

The analysis also revealed statistically significant differences in assessment method choices based on teaching domains (H(3) = 124.784, p = .001, η^2 = .10). Vocational subject teachers (M = 591.93) most frequently used seminar paper assessment, reflecting the specificity of vocational education, in which seminars are a common way of assessing practical skills and knowledge related to the chosen profession. Social science teachers (M = 472.69) and natural science teachers (M = 465.79) used this method less frequently, possibly reflecting the nature of their subjects, which require other appropriate assessment methods. Primary school teachers (M = 295.25) used seminar assessments least frequently, which may be related to the adaptation of assessment methods to the age group and developmental characteristics of younger students at this educational level. The relatively large effect size (η^2 = 0.10) in this analysis suggests that 10% of the variance in the frequency of seminar paper assessments among the different groups of teachers can be attributed to their teaching domain. This suggests that the teaching domain has a considerable influence on the choice of this assessment method. Despite the observed differences, factors other than the teaching area could also affect teachers' assessment preferences.

Similarly, significant differences were observed in the use of assessment of authentic tasks, video productions, and projects were observed (H(3): 17.503, p = .001, η^2 = .02). Vocational subject teachers (M = 507.60) frequently emphasized practical skills, best assessed through authentic tasks, video productions, and projects. Social science teachers (M = 484.33) also frequently used this method, possibly to encourage critical thinking and idea expression. Natural science teachers (M = 441.34) used it less frequently, possibly due to a greater emphasis on concrete scientific concepts. Primary school teachers (M = 406.52) used this assessment method least often, likely due to the constraints of conducting such assessment formats with younger students. The effect size suggests that the teaching domain accounts for 2 % of the variance in the use of authentic tasks, video productions, and projects for assessment, suggesting that other factors contribute significantly to this choice and thus further research is needed.

A Dunn's post-hoc test aimed to compare the assessment practices of natural science with those from other

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fields in new educational environments. The results suggest that natural science teachers' assessment methods in these contexts do not significantly differ from other teachers. However, some notable differences emerged in specific assessment types. Regarding oral assessment, a statistically significant difference was found between natural science teachers and social science teachers (p = .008, $M_{natural\ science}$ = 2.35, $M_{social\ science}$ = 2.62). Natural science teachers tended to use oral assessment less frequently compared to their counterparts in social science. In the case of quizzes, significant differences were observed between natural science teachers and primary school teachers (p = .009, $M_{natural\ science}$ = 2.26, $M_{primary\ school}$ = 1.91) as well as social science teachers (p = .007, $M_{natural\ science}$ = 2.26, $M_{social\ science}$ = 1.96). Regarding written assessment, statistically significant differences were seen in comparison with primary school teachers (p = .001, $M_{natural\ science}$ = 1.63, $M_{primary\ school}$ = 1.17). Natural science teacher teachers tended to use written assessments more frequently than primary school teachers. For the assessment of seminar papers, differences were found between natural science teachers and primary school teachers (p = .001, $M_{natural\ science}$ = 1.94, $M_{primary\ school}$ = 1.29), as well as vocational subject teachers (p = .001, $M_{natural\ science}$ = 1.94, $M_{primary\ school}$ = 1.24). Natural science teachers used assessment of seminar papers more frequently compared to primary school and vocational subject teachers. However, no statistically significant differences were observed in the use of authentic tasks among natural science teachers and teachers from other fields. In summary, while natural science teachers did not significantly differ from teachers in other fields in terms of general assessment practices in new environments, they showed variations in specific assessment methods like oral assessments, quizzes, written assessments, and assessment of seminar papers when compared to their colleagues in primary school and social science, as well as vocational subject teachers.

Discussion

The purpose of this study is to examine science teachers' preparedness for assessment in the age of AI, considering the challenges and opportunities presented by the ubiquitous presence of AI technologies in education (Cotton et al., 2023). Although the results were analyzed from the perspective of self-assessment during periods of emergency remote teaching, the findings suggest that factors beyond the teaching domain also play significant roles in determining teachers' choice of assessment methods. These conclusions are further discussed through the lens of assessment in the age of AI.

Based on the theoretical framework of the research conducted, it is hypothesized that teachers, in general, are not adequately prepared for assessment in the era of widespread accessibility of AI. In line with the theoretical underpinnings of the study, which highlights the need for new forms of knowledge, new forms of learning, new forms of teaching, and consequently new forms of assessment, it was expected that teachers would predominantly report choosing conventional assessment methods during emergency remote teaching. This period opened the door to computer-based learning and new forms of assessment in schools (Khan et al., 2023). Results show that teachers most often chose to use oral assessment via video conferencing during distance assessment. This method was instrumental in curbing potential plagiarism and other forms of cheating that students might employ in assessing their curriculum goals. Oral assessment is considered one of the fundamental forms of conventional assessment, alongside with written assessment, which was used least frequently during remote teaching due to concerns of plagiarism and cheating. Oral assessments can be successful and necessary in contemporary learning environments when they promote self-reflection, performance-based assessment, and peer assessment (Crawford et al., 2023; Gimpel et al., 2023). To a slightly lesser extent, but still infrequently, teachers chose to assess authentic tasks, video productions, and projects, which are forms of assessment anticipated to be foundational in future assessments. Teachers were somewhat less inclined to assess seminar assignments, which became problematic in the age of AI because students could complete the entire assignment using AI. Teachers' responses indicate that they are not fully prepared for assessment in the age of widespread AI in education, underscoring the need for enhanced teacher preparation for AI use in assessment. Adequate training and support for teachers are essential to help them navigate the challenges and harness the opportunities that AI technology presents in education, as it becomes evident that they are not yet ready for it (Kerneža et al., 2023). Adapting educational practices and policies to the evolving technological landscape of education triggered by distance learning (Gurajena et al., 2021) is crucial for achieving teacher readiness for assessment in the age of AI.

The results indicate that differences exist in the assessment approaches adopted by teachers during remote education, contingent on their primary area of instruction. Oral assessment via videoconferencing was most frequently chosen by social science teachers, less so by natural science and vocational teachers, and least by primary school teachers. The predilection for more interaction and discussion in social science subjects might explain this

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trend, while natural science subjects entail more hands-on demonstrations or experiments, challenging to execute in a virtual milieu. Quizzes and assignments were predominantly utilized by natural science and vocational teachers to assess student knowledge, and least by social science and primary school teachers. Natural science and vocational teachers appear to emphasize the practical application of knowledge, assessable through assignments and quizzes, whereas social science and primary school teachers seem to prioritize conceptual understanding, assessable through alternative assessment forms. Written assessments were predominantly chosen by vocational teachers, less so by natural science and social science teachers, and least by primary school teachers. The variance in the preference for written assessment among different subject teachers could stem from the intrinsic nature of the subject and the imperative for written articulation of knowledge. Vocational subjects might necessitate extensive writing and formulation, aligning with conventional assessment methods (Montgomery, 2022) pertinent to skills typically not computer based (Swiecky et al., 2022). In contrast, social science subjects might emphasize argumentation and essay writing. Science problems are more easily assessed using alternative methods, potentially explaining why natural science teachers infrequently opt for written assessment. Assessment of seminar papers was most prevalent in vocational subjects, less so in social studies and natural science subjects, and least in primary school subjects. Vocational students might develop seminar papers emphasizing practical examples and real-world knowledge applications, while social science subjects might focus on data presentation, and natural science subjects on experimental work. Conversely, primary school students, especially in the early years, might not possess the requisite skills for independent seminar paper production. Authentic tasks, video productions, and projects were predominantly chosen by vocational and social science teachers, less frequently so by natural science teachers, and least by primary school teachers. This aligns with the practical and analytical skills students demonstrate in such assignments. Natural science subjects might necessitate experimental work or the creation/presentation of a scientific research project. Science teaching involves intricate concepts that students encounter and explore in school, with optimal teaching and learning defined by higher taxonomic levels (CAST, 2018). Primary school teachers, who also teach science, were observed to seldom use authentic tasks, video productions, and projects. Given the younger age of these students, it is not anticipated that these tasks and related skills are as developed as in older students. However, it becomes imperative to ascertain whether teachers are fostering basic digital literacy skills in students, preparing them for advanced assessment at the secondary level. Primary education is a pivotal juncture in establishing the foundation for teaching contemporary 21st-century learning environments (Kerneža & Kordigel Aberšek, 2023; Kordigel Aberšek & Kerneža, 2023).

Considering the research findings that address potential disparities between science teachers and educators from other disciplines concerning assessment practices in the age of pervasive AI accessibility and the unparalleled innovations in science and technology, as highlighted by OECD (2018), some differences were noted in the selection of assessment methods based on the educators' primary instructional domain. Social science teachers predominantly opted for oral assessments via videoconferencing, suggesting an amplified necessity for interaction and discourse within social science disciplines. In contrast, science and vocational subject teachers frequently employed quizzes and assignments as assessment tools, potentially reflecting the accentuation of knowledge's practical application within this domain. Vocational teachers exhibited a marked preference for written assessments, whereas their counterparts in the social sciences appeared to prioritize argumentative and essay-based evaluation. Science teachers demonstrated a reduced inclination towards written assessment, possibly due to the efficacy of alternative methods in evaluating scientific queries. The assessment of seminar papers was predominantly observed within the vocational subjects, facilitating students in showcasing practical knowledge applications in real-world context. Primary school teachers exhibited a reduced propensity for this assessment form, attributing this to the perceived underdevelopment of independent seminar paper production skills among primary students. Authentic tasks, video productions, and projects were predominantly favored by vocational and social science educators, mirroring the practical and analytical proficiencies students manifest in these tasks. Science teachers displayed a diminished preference for these assessment methods, potentially due to the inherent requirements of experimental undertakings or the formulation of scientific research projects, which might be deemed unsuitable for primary school students lacking the requisite competencies for autonomous task execution.

The findings from the research highlight the varying degrees of teacher readiness and their inclinations towards certain assessment methods during remote teaching. These can be interpreted through the lens of potential receptiveness to AI-driven innovations. Such receptiveness is not merely a reflection of adaptability to new technologies but also an indication of pedagogical flexibility and willingness to evolve in response to the changing educational landscape. Insights from the research phase suggest that the experiences and feedback of

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teachers during distance education can provide valuable context when considering the broader implications of AI-driven assessment. For instance, the challenges faced, the solutions devised, and the overall sentiment towards technology-mediated teaching can serve as indicators of how educators might approach and integrate AI tools in their teaching and assessment practices. Moreover, the nuances of experiences during remote teaching, such as preferences for certain assessment methods or reservations about others, can offer clues about potential areas of comfort or concern when it comes to AI-driven assessment. This perspective is further supported by recent research, including the works of Salas-Pilco, Xiao, and Hu (2022). Their findings emphasize the multifaceted nature of teacher readiness, suggesting that it's not just about technological proficiency but also about pedagogical understanding, attitude towards innovation, and the ability to foresee the potential challenges and benefits of integrating AI. Collectively, these insights paint a comprehensive picture of the evolving landscape of AI in education, emphasizing the intricate interplay between technology, pedagogy, and the requisite preparedness of educators.

The data highlight the imperative for literacy skills that are essential for participation in various assessment activities, encompassing oral evaluations, reading assignments, essay writing, or comprehension of instructions. Teachers must recognize the significance of fostering students' literacy skills and catering to their diverse reading and writing requirements within the assessment context. Such an approach not only renders learning meaningful but also proffers students with significant and rigorous learning prospects, as underscored by CAST (2018). This is especially pronounced in primary schools, where the same teacher assesses both science and literacy, given the low reading scores shown in the new PIRLS data analysis (Mullis et al., 2023). This ensures equitable and quality knowledge assessment in the AI epoch, wherein the widespread availability of AI technologies in education represents merely one facet of the myriad opportunities and challenges confronting teachers. The connection between literacy and science instruction is crucial, as evidenced by other studies (e.g., Kim et al., 2021; Pearson et al., 2010). Grasping content and critical interpreting of scientific texts are vital for students' academic success in science, given their exposure to a plethora of scientific texts that often contain complex concepts, scientific language, and specific terminology. Proficiently navigating scientific literature is paramount for information assimilation, key idea identification, detail discernment, and holistic subject comprehension. Within contemporary assessment frameworks, students must be able to evaluate the credibility of sources, recognize scientific bias, analyze, and evaluate arguments, and identify possible errors or gaps in research. This requires developed critical thinking supported by advanced reading and writing skills. Following the process of data collection, students should articulate their perspectives coherently and systematically, defending their viewpoints and discoveries. Written expression skills include appropriate use of scientific language, text organization, logical connections, and use of appropriate scientific and technical terms. In summary, the teaching and assessment of science in the age of AI encompasses the full spectrum of both literacy and scientific content. In a modern science classroom supported by AI, the development and support of literacy skills are crucial. Students must have the opportunity to develop comprehension, critical reading, summarizing, and analytical thinking skills in the specific context of science content. This prepares them with the skills essential for active participation in assessment activities demanding the interpretation and application of scientific data. Students should instruct students to critically evaluate sources and information they obtain from the Internet, which should also be given more attention by teachers (Zemljak & Kerneža, 2023). A potential strategy is delineated by Leu et al., (2008) with the three-phase model of online reading instruction called Internet Reciprocal Teaching (IRT), resonating with the tenets of problem-based learning (Zemljak et al., 2023). This approach facilitates student collaboration, fostering critical thinking and problem-solving skills, with an emphasis on the learning trajectory rather than mere outcomes. Students need empowerment within the learning paradigm, given that the learning process itself constitutes a pivotal contribution to pragmatic life knowledge- Thus, education can be perceived as a life experience, encompassing attitudes, knowledge, and skills, tailored *for life-encompassing* behavior, cognition, and consideration (Broks, 2023).

Children today live in a very different world than their parents (Siraj, 2017). Not only do today's children not know the time before smart devices; they are also the first generation whose lives are in one way or another defined by AI-enabled applications and devices, while also being exposed to AI-related risks (UNICEF, 2020). The research provides insights into the need for training and support for teachers in the use of AI in assessment, but further study is needed to provide a more concrete and reliable picture of teacher readiness in this area. If Turetzky et al., (2019) were already calling for AI researchers to become AI educators in 2019 and create resources to help teachers and students understand AI intelligence, this is even more important in 2023. Kerneža (2023) noted that pre-service teachers frequently overestimated the competencies essential for interpreting chatbot-generated content, a perception that often diverged from evaluators' assessments. Such disparities might have led to potential

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misjudgments of their capabilities or suboptimal evaluations, potentially curtailing their progression opportunities. This reinforces the findings outlined by Farell (2007) that teachers need to continually revise their knowledge of teaching and learning to teach effectively and competently in the rapidly changing field of education. With additional research and analysis focused directly on AI's role in assessment, more definitive conclusions can be drawn regarding teacher readiness in this sphere, facilitating the proposition of suitable strategies and interventions to recalibrate educational practices. Our responsibility as individuals is to ensure the ethical development and application of AI (Dignum, 2019). Therefore, as UNESCO (Miao et al., 2020) emphasizes it is particularly important, that AI supports and promotes children's growth. More than ever, education must become more systemic through a balance between technological and humanitarian education. Today, we need to find better ways to combine our physical and spiritual pursuits, which is the fulfillment of a truly sustainable (balanced, long-term) development of our way of life and our future education (Broks, 2016). Furthermore, it is important to emphasize that, as UNESCO (Miao et al., 2020, p. 39) point out, the teacher must support children's development and well-being; ensure inclusion of and for children; prioritize fairness and nondiscrimination for children; protect children's data and privacy; ensure children's safety; provide transparency, explainability, and accountability for children; prepare children for current and future developments in AI; equip governments and businesses with knowledge about AI and children's rights; and create an enabling environment for child-centred AI. This can only be achieved through an AI-competent teacher.

The uniqueness of this study lies in its emphasis on the readiness of science teachers for assessment in the age of AI. While there have been studies on the use of AI in education and its impact on student learning, this research specifically addresses teachers' readiness to use AI-based assessment methods. By examining teachers' perspectives and practices, it sheds light on the current state of their readiness and highlights areas that need further attention and support. This focus on teacher readiness in the context of AI assessment sets this study apart from others. The implications of the study also extend to the broader educational community, highlighting the need for professional development programs, subject-specific adaptations of AI-based assessment, and the integration of literacy into assessment practices. By considering these implications, the findings can contribute to the effective and ethical implementation of AI in education, ultimately benefiting student learning outcomes.

The limitations of the study are also considered in the analysis of the results and discussion. A non-probability sample was used for the study, which may lead to selective participation and potential bias, as only those teachers who are more interested in the topic or have experience may have chosen to participate. Therefore, the generalizability of the results should be taken with caution, as they may be more representative of this group of teachers. With respect to the administration of the questionnaire, it is also important to consider the possibility that teachers may have provided subjective responses that are consistent with socially desirable responses or idealized perceptions of their work. There are also concerns about the accuracy of self-reflection. In addition, it is important to note that the study was conducted during a time when teaching occurred remotely, which may have influenced teachers' perceptions, instructional decisions, and willingness to adopt new assessment methods. Therefore, the application of the study's findings under "normal" circumstances should be carefully considered.

Conclusions and Implications

This research highlights the need for better preparation and support of teachers in the use of AI in assessment. Despite the challenges and opportunities AI presents in education, teachers predominantly chose conventional assessment methods during emergency remote teaching. This approach helped address concerns about plagiarism and cheating. However, the assessment methods teachers chose varied depending on their primary subject. Certain assessment methods were preferred across subjects, such as quizzes and assignments in natural science and vocational subjects and written assessments in vocational subjects. Primary school teachers were less likely to use certain forms of assessment because of the age and readiness of their students. The study also highlights the importance of literacy skills and their connection to science education.

The findings suggest that teachers are not fully prepared for assessment in the era of widespread availability of AI technologies. Understanding teacher readiness for assessment using AI is critical to the successful adaptation of this technology in education. Only with adequately trained teachers can we ensure that AI serves as a tool to enhance the learning process and not as a substitute for teacher expertise. Professional development programs, subject-specific adaptations of AI-based assessment, and the integration of literacy into assessment practices are essential to ensure the effective implementation of AI in education. To further this goal, it is recommended that

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future efforts be directed towards the development of comprehensive educational programs and materials. For the organization of the educational process, it is recommended that ongoing professional development programs focused on the use of artificial intelligence in assessment are introduced. Additionally, it is suggested that additional resources and tools are provided for teachers to assist them in adapting to new technologies and assessment methods. In the context for planning further research, it is proposed that studies be conducted to directly assess specific teacher skills reflecting their readiness to work in the reality of artificial intelligence. Such studies would allow for a more precise understanding of where the exact shortcomings lie and how best to address them. This will ensure that teachers are not only introduced to AI but are also equipped to utilize it effectively in their teaching practices.

As we stand at the brink of an educational shift powered by artificial intelligence, the readiness of our teachers is the key to its success. The interplay between traditional teaching methods and emerging AI technologies is intricate, and it's up to us to ensure this collaboration is seamless. The future of education, shaped by AI, will be as strong as the foundation we lay today. Thus, investing in our teachers' preparedness is not just a necessity but a commitment to a brighter, more informed future.

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Declaration of Interest

The authors declare no competing interest.

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EXPLORING LOWER-SECONDARY SCHOOL STUDENTS' SYSTEMS THINKING PERFORMANCE IN ECOLOGICAL ISSUES

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Abstract. *Exploring students' systems thinking (ST) is essential in enhancing science learning, but existing studies have failed to understand students' ST fully as it relates to ecological issues. This study aimed to fill the aforementioned literature gap by exploring lower-secondary school students' ST regarding ecological issues. The Systems Thinking Test regarding Ecological Issues, which measures four ST skills (system organisation, behaviour, application, and evaluation), was administered to 1,092 lower-secondary school students. The results reveal low ST performance in ecological issues, with students finding it particularly difficult to identify interactions among components and understand system characteristics. Furthermore, most lacked reflective consciousness and consideration of the diverse dimensions of ecological issues, resulting in monocausal reasoning in system decision-making and evaluation. Comparatively, urban school students performed better than their rural counterparts; additionally, an item-level analysis revealed that climate warming was challenging for the students to understand. This study suggests that greater efforts should be made to address students' drawbacks and that multi-perspectival teaching is necessary in the context of ecological issues. The addition of system decision-making and evaluation in assessments can enable a broader understanding of ST.*

Keywords: *environment education, lower-secondary school, partial credit model, sustainable development, systems thinking*

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Introduction

Human activities such as deforestation, overfishing, and environmental pollution have endangered the survival of many species; for example, commercial whaling and marine garbage have brought whales close to extinction. To achieve a harmonious co-existence of humanity and nature, the United Nations has launched a program titled 'Education for Sustainable Development'. Accordingly, understanding of ecological issues, such as climate change and biodiversity loss has become particularly stressed in environmental education and sustainable development (Mambrey et al., 2022), and the ecosystem has emerged as an important aspect in international science curricula (Australian Curriculum, Assessment and Reporting Authority, n.d.; Ministry of Education, & P. R. China, 2022; Next Generation Science Standards Lead States, 2013).

Ecological issues refer to environmental problems concerning organisms, and their interactions with each other and the environment (Ecology Center, 2023). These are complex systems that are difficult to understand, because of the inherent intricacies, and long-term effects of human actions (Fanta et al., 2020). Multiple dimensions (e.g., social, economic, and socio-cultural elements) must be considered for identifying the consequences of such issues (Fanta et al., 2020; Ke et al., 2020; Riess & Mischo, 2010; Schuler et al., 2018). However, students lacking a systematic perspective cannot fully appreciate these issues (Ke et al., 2020; Liu et al., 2011; Yang, 2005). To solve these issues effectively, students need the systems thinking (ST) skills (Hogan, 2002; Mambrey et al., 2022; Riess & Mischo, 2010) that are emphasized in international science education documents (e.g., National Research Council, 2010; Next Generation Science Standards Lead States, 2013). ST is the skill to reason about complex systems in accordance with system characteristics to create a holistic understanding of various phenomena for problem-solving and system evaluation (Fanta et al., 2020; Gilissen et al., 2020; NRC, 2010). Researchers in various fields advocate the necessity to promote students' ST in science learning (Gilissen et al., 2020; Schuler et al., 2018; Sommer & Lücken, 2010; Verhoeff et al., 2018). Moreover, complex and diverse perspectives of ecological issues would allow students to engage in ST about broader issues, and ultimately achieve global citizenship literacy (Ke et al., 2020; Lee et al., 2013; Sadler et al., 2007). Thus, it is essential to explore and develop students' ST in the context of ecological issues.

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ST in the Ecological Context

According to previous studies, ST in science education incorporates not only the skill to identify interactions among system components and understand system characteristics (Ben-Zvi Assaraf & Orion, 2005; Brandstädter et al., 2012; Mehren et al., 2018; Sommer & Lücken, 2010) but also the skill to make predictions, decisions, and judgement based on system analysis (Ben-Zvi Assaraf & Orion, 2005; Evagorou et al., 2009; Mehren et al., 2018; Riess & Mischo, 2010) and make evaluations on the validity of system structures, decision-making, and the limitations of predictions (Fanta et al., 2020; National Research Council, 2010; Rosenkränzer et al., 2017).

Given that multiple components and interactions of ecosystems must be considered, studies have mostly focused on students' understanding of interdependent relations in ecosystems; for example, assessments of elementary school students require them to reason about food webs (Hokayem & Gotwals, 2016; Mambrey et al., 2020; Mambrey et al., 2022). At the secondary level, they focus on students' scientific explanations of ST concepts regarding ecosystems (e.g., indirect connections, feedback loops, and emergent properties) (Jin et al., 2019). However, these studies failed to cover the full range of ST skills needed by students for understanding and solving complex ecological issues, especially for making decisions and evaluating on the basis of system analysis. Although the direct impact of human actions on ecosystems has been incorporated in the assessment (Jin et al., 2019), it failed to provide opportunities for students to consider the other dimensions (e.g., society, economy, and socio-culture) indirect effects on causing or solving ecological problems.

Research on Lower-secondary School Students' ST Levels

Most studies (e.g., Hokayem & Gotwals, 2016; Jin et al., 2019; Mehren et al., 2018) have assumed that there is a gradual increase in the development of students' ST skills through learning progressions (LPs). Some researchers have defined ST using a three-level hierarchical model (from low to high), namely, analysis of system components, synthesis of system components, and problem-solving (Ben-Zvi Assaraf & Orion, 2010). Jin et al. (2019) defined a four-level LP for ST in an ecosystem based on students' response complexity patterns; the four levels are called no ideas (Level 1), individual organisms (Level 2), relationships and patterns (Level 3), and mechanisms (Level 4). Mehren et al. (2018) differentiated systems-thinking levels according to system complexity, including the number of components and interrelations, type of relations, and dealing with system properties.

Only a few ST measurements at the lower-secondary school level exist, especially for large groups of students (Brandstädter et al., 2012). Existing studies indicate a low starting point for ST among young students with regard to various fields. A small sample study of the hydro-cycle system indicated a relatively low performance of lower-secondary school students regarding ST skills in general (Ben-Zvi Assaraf & Orion, 2005). A small-scale comparison of the skill of understanding complex systems between experts and Grade 7 students using the Structure–Behaviour–Function model implied that novice students focused on the structural level (Hmelo-Silver & Pfeffer, 2004). An assessment of ST regarding ecosystems has revealed that most secondary school students tend to identify direct and indirect relationships (Jin et al., 2019). However, the specific difficulties hindering lower-secondary school students' ST in the context of ecological issues remain unclear.

Studies have also revealed a great improvement in ST performance following the introduction of teaching interventions at the lower-secondary school educational level (Ben-Zvi Assaraf & Orion, 2005; Hmelo-Silver et al., 2017; Riess & Mischo, 2010); this indicates the feasibility and potential of developing lower-secondary school students' ST.

Students' ST Performance in Different Groups

For a comprehensive evaluation of ST, it is important to detect differences in students' average performance among different subgroups. However, this question has not been sufficiently explored in ST research (Cox et al., 2019; Jin et al., 2019).

Gender science stereotypes have long been discussed; females are still considered to be underrepresented in different science fields (Brotman & Moore, 2008). However, the effect of gender on ST is unclear; research in different scientific contexts has yielded distinct results. A study conducted in engineering found that male students performed significantly better than female ones (Sweeney & Sterman, 2000). However, research on ecosystems and geographical systems has suggested no significant differences based on gender (Cox et al., 2019; Jin et al., 2019). Mambrey et al. (2020) found a similar reasoning pattern in elementary and lower-secondary school students, sug-

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gesting that the ST of young students regarding ecosystems was independent of their age. However, a significant difference was found with respect to geographical ST between grades, especially among high school students (Cox et al., 2019). Research has found significant performance gaps in ST among schools from different locations in the United States (Jin et al., 2019). Because the above-mentioned studies have shown distinct results in different system-specific contexts, it is necessary to check the effects of the aforementioned variables on students' ST performance in the more complex context of ecological issues involving interactions between humans and ecosystems.

Research Aim and Questions

A full picture of students' ST regarding ecological issues is essential for promoting ST to achieve sustainable development. However, the existing studies failed to cover the full range of ST skills and the specific weaknesses that hinder students' development of ST. Moreover, it remains unclear in the literature whether students are able to contemplate the various dimensions involved in these complex issues. Thus, this study aimed to supplement the missing content by comprehensively evaluating on a large scale lower-secondary school students' ST regarding ecological issues. The following were the research questions for this study:

1. What is the current level of ST regarding ecological issues among lower-secondary school students?
2. In which specific aspects of ST regarding ecological issues do students experience the most problems?
3. How do students from different groups differ in their ST performance?

Research Methodology

Description of the Test to Measure Students' ST

The authors constructed a systems thinking test regarding ecological issues (STTEI) based on Mehren et al.'s (2018) ST framework; it incorporated comprehensive ST skills based on the latest insights from ST studies and was empirically validated in the context of geography and ecology (Mambrey et al., 2020). The items of the STTEI measured four skills in ST, which we regard as covering the full range of skills included in the existing literature (Ben-Zvi Assaraf & Orion, 2005; Brandstädter et al., 2012; Evagorou et al., 2009; Fanta et al., 2020; Mehren et al., 2018; National Research Council, 2010; Riess & Mischo, 2010; Sommer & Lücken, 2010), namely, system organisation, system behaviour, system application, and system evaluation. Items in system organisation refer to identifying ecosystem components and the interrelations among components. Items related to system behaviour require students to analyse the results of system changes based on the interactions involved and their understanding of the system characteristics. To apply the system, students were asked to make predictions and decisions based on a system-effect analysis. For the last skill, students were required to work on problems and determine the validity of the system structure, decisions made, and limitations of predictions. Second, these ST skills were differentiated into three levels based on performance complexity according to system-related structural and behavioural complexity, as described by Mehren et al. (2018). These levels are described below.

Level 1: Students identify low numbers of elements and isolated or monocausal relationships. Students' analysis and reasoning regarding systems are based on monocausal relations.

Level 2: Students identify a moderate number of elements and linear–indirect relationships. The analysis and reasoning are based on linear and indirect relationships.

Level 3: Students identify a large number of elements and complex or nonlinear relations. Students perform analysis and reasoning based on nonlinear and complex relations.

The STTEI comprised 13 items (ordered multiple choice, short answers, two-tied items, and extended response questions) to probe different levels of students' ST about ecological issues, and each item was allocated to one skill (Table 1). As climate change and sustainability problems have been the most prevalent ecological issues in the last decade (Fanta et al., 2020; You et al., 2018), the test was about issues highlighting sustainability as the context that could provide students with opportunities to explore multiple dimensions in ecological issues (e.g. climate warming, sustainable rainforest development, overfishing, industrial pollution, abuse of pesticides, and the absence of top predators). Items were scored using 0–2 or 0–3 point ranges according to the three levels of performance complexity. The two tied items and extended response questions gave students the opportunity to express their explanations of ecological issues. The concept map (CM) item is an example of an extended response question

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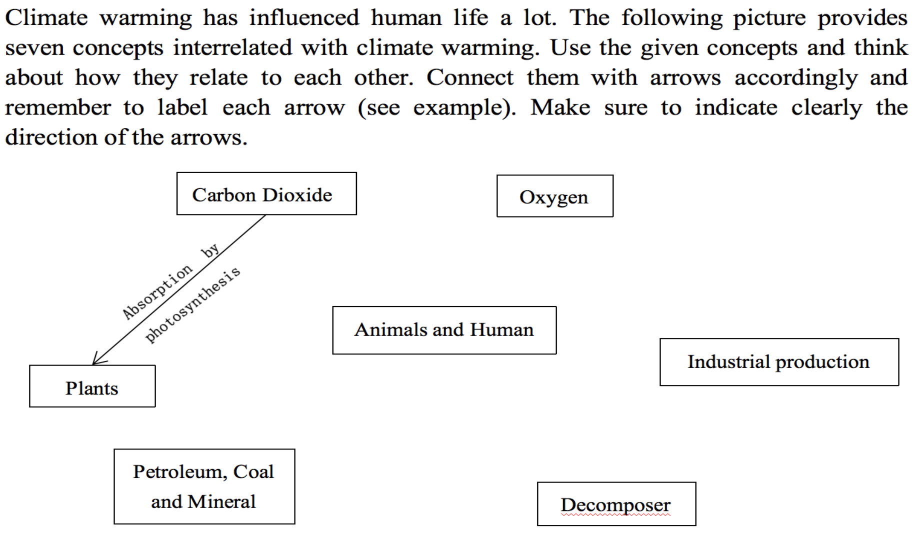
(Figure 1). It was designed based on the context of climate warming to assess the extent to which students identify interrelations among components related to climate warming. The provided concepts included both biotic and abiotic components. The social element (industrial production) was included in this item. The other items of the STTEI are presented in the Appendix.

Figure 1
Concept Map Item (Item 5)



To ensure content validity, the item content and wording were evaluated and revised by expert review. A quantitative pilot test (n = 97) was conducted to validate the test instrument, and the Rasch partial credit model (PCM) was used to examine item fit statistics to address construct validity. Three items in the original version were eliminated because of low item discrimination (below .2). Subsequently, a field test (n = 456) was conducted to validate further the 13-item test. The expected a posteriori (EAP) reliability was .8, indicating acceptable internal consistency, and all items' mean-squares fell into the suitable range of .7 to 1.3 (Bond & Fox, 2007).

Table 1
Specific Information of Test Items

Skills required		Item context	Item number
System organisation	Identify system components	Pond ecosystem	Item 1
	Identify interrelations among components	Climate warming	Item 5
System behaviour	Understand emergence	Ecological equilibrium	Item 3
	Dynamic change	Absence of top predators	Item 8
	Identify feedback loop	Temperature change in forests	Item 11
	Cyclic thinking	Nutrition cycle	Item 10
System application	Make predictions	Industrial pollutant, Climate warming	Item 2 Item 6
	Make decisions	Climate warming, Sustainable development of rainforests	Item 7 Item 12
System evaluation	Evaluate the system structure	Overuse of pesticides	Item 4
	Determine the validity of the system structure, decisions, and limitations of predictions	Absence of top predators Overfishing problems	Item 9 Item 13

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Participants and Data Collection

A sample representative of the diversity of lower-secondary school students is required to obtain more robust statistical results and meet the purpose of the study, such as the requirement of comparing students' performance across genders, grades, and school locations. Thus, six lower-secondary schools in southern and northern regions of China were purposefully sampled. These schools varied in school settings, educational resources, and socio-economic status. According to the previous study, the sample size is determined by the standard error of measures, which should exceed the minimal requirement of 267 (Liu, 2020; Wu et al., 2016). In order to improve the accuracy of measurement, the sample size is four times larger than the required minimal sample size (the standard error of Rasch measures less than .1). All participants in these schools possessed knowledge about the ecosystem; a total of 1,183 students from Grades 7 and 8 involved in the study. After eliminating blank and invalid responses, information from 1,092 students was used for the analysis (Table 2).

Data were collected from November 2022 to December 2022. The purpose of the study and test content were reported to school principals to acquire permission. All students and teachers participated in the study voluntarily, and the test was conducted anonymously to protect students' privacy. The teachers ensured that students completed the test within 45 minutes. Before the test, teachers informed students of the aim of the test and that the results would be used exclusively for scientific research purposes. The teachers also promised students that their test performance would not affect their subject grades and encouraged them to write down their honest thoughts as much as possible.

Table 2
Demographic Data of the Participants

Demographic categories		Number of students	Percentage (%)
School location	Urban schools	592	54.2
	Rural schools	500	45.7
Gender	Male	565	51.7
	Female	527	48.2
Grade	Grade 7	568	52
	Grade 8	524	47.9

Data Scoring and Analysis

The developed scoring rubrics were used to score all students' responses. Ten percent of the randomly selected tests were scored by two independent raters (a PhD student and a lower-secondary school biology teacher) to check inter-rater reliability. An inter-rater reliability analysis using kappa statistics determined the consistency between raters, and the kappa's range was .62–.85, with a median of .75 (Cohen, 1968), indicating substantial agreement for each item from different raters (Landis & Koch, 1977).

This study used PCM analysis via the Test Analysis Module package in R software (Robitzsch et al., 2021) to establish the participants' ST levels on the test, as it has been deemed suitable for analysing polytomous data. The reliability of the EAP estimates was checked, and the weighted likelihood estimates (WLEs) were used as student proficiencies. A Wright (person–item) map was generated to quantify the locations of item difficulty and student performance on the same logit scale. The *t*-test was used to compare performances between the different sub-groups of participants (e.g., male vs. female). Differential item functioning (DIF) was applied to examine differences between student groups at the item level to provide further information on weaknesses and strengths with regard to students' ST (Wu et al., 2016).

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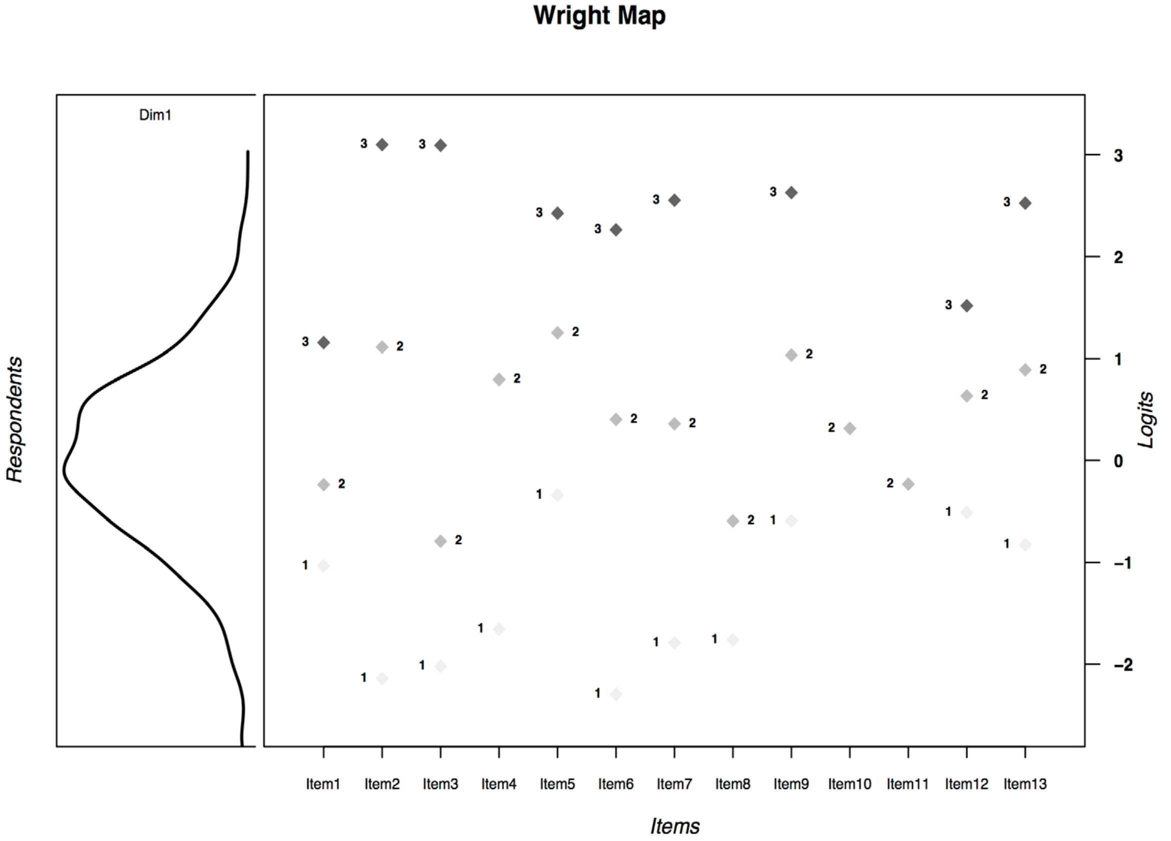
Research Results

Students' Overall Performance in ST Regarding Ecological Issues

In Figure 2, the left side of the Wright map displays the density distribution (which approximates a normal distribution) of the student performance (WLEs) on the test. The right side represents the distribution of the Thurstonian thresholds for each item. A comparison of the WLEs and item thresholds showed that only a small proportion of students had more than a 50% chance of achieving the third level (Figure 2).

Figure 2
Wright Map for ST Regarding Ecological Issues



Note. 1 = threshold value 1, 2 = threshold value 2, and 3 = threshold value 3.

The threshold values of each item level were calculated using PCM analysis (Table 3), and the mean threshold values of the item responses belonging to the same level across the ST skills were calculated (Wang & Song, 2021). The mean of the students' ability measures (WLEs) was compared with the mean threshold values of the different levels; when the mean WLEs exceeded the latter, it was determined that the student had reached a specific ST level. As shown in Table 3, the student ability measures reached, on average, Level 1 for each skill, and Level 3 was the most difficult to achieve for each skill. The students' mean ability (*M* = .047) for system organisation was higher than that for the other three skills.

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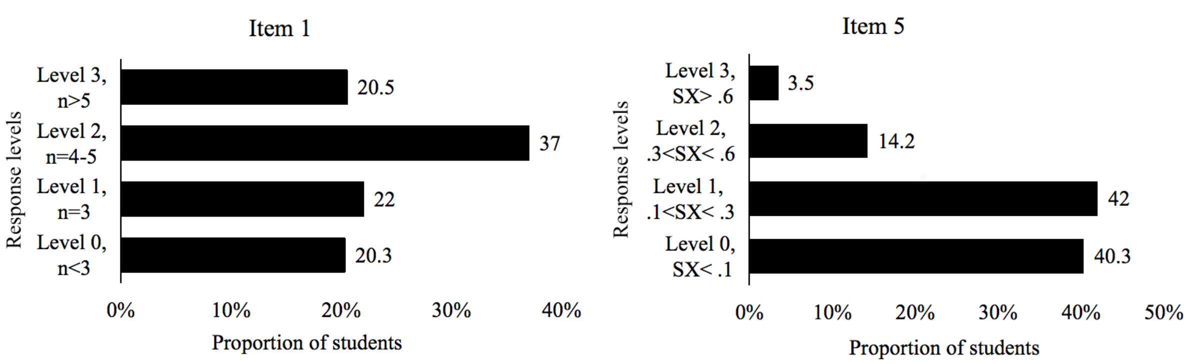
Table 3
Mean Threshold Values of Every Performance Level across ST

Skill	Level	Items and threshold values on different levels	Mean Threshold values	Participant ability
System organisation	Level1	I1(-1.034); I5(-.341)	-.688	.047
	Level2	I1(-.238); I5(1.253)	.508	
	Level3	I1(1.156); I5(2.426)	1.791	
System behaviour	Level1	I3(-2.02); I8(-1.760)	-.926	-.014
	Level2	I3(-.793); I8(-.594); I10(.313); I11(-.232)	.070	
	Level3	I3(3.092)	3.092	
System application	Level1	I2(-2.141); I6(-2.294); I7(-1.791); I12(-.512)	-1.685	-.009
	Level2	I2(1.112); I6(.402); I7(.359); I12(.633)	.627	
	Level3	I2(3.099); I6(2.263); I7(2.554); I12(1.519)	2.359	
System evaluation	Level1	I4(-1.656); I9(-.592); I13(-.828)	-.575	-.004
	Level2	I4(.794); I9(1.034); I13(.888)	1.619	
	Level3	I9(2.629); I13(2.525)	2.577	

Difficulties Experienced with Regard to Different ST Skills for Ecological Issues; Ability to Identify Components and System Interactions

The analyses of the students' identification of components in the pond ecosystem (Item 1) indicated that most students (57.5%) correctly identified a moderate (Level 2) or high (Level 3) number of elements (Figure 3). However, one-fifth of the students could not correctly identify the system components. The analyses of students' wrong answers indicated that they had some misconceptions regarding hidden elements; for example, the students confused 'green algae' with 'bacteria' and sorted 'bacteria' into the producer and 'green algae' into the decomposer categories. Furthermore, some students misclassified 'bacteria' as an abiotic factor in the pond ecosystem.

Figure 3
Distribution of Students' Responses on Items 1 and 5



Note. n = number of components. The structural index (SX) = sum of all arrow strings, branches, and cycles / the number of concepts (Mehren et al., 2015).

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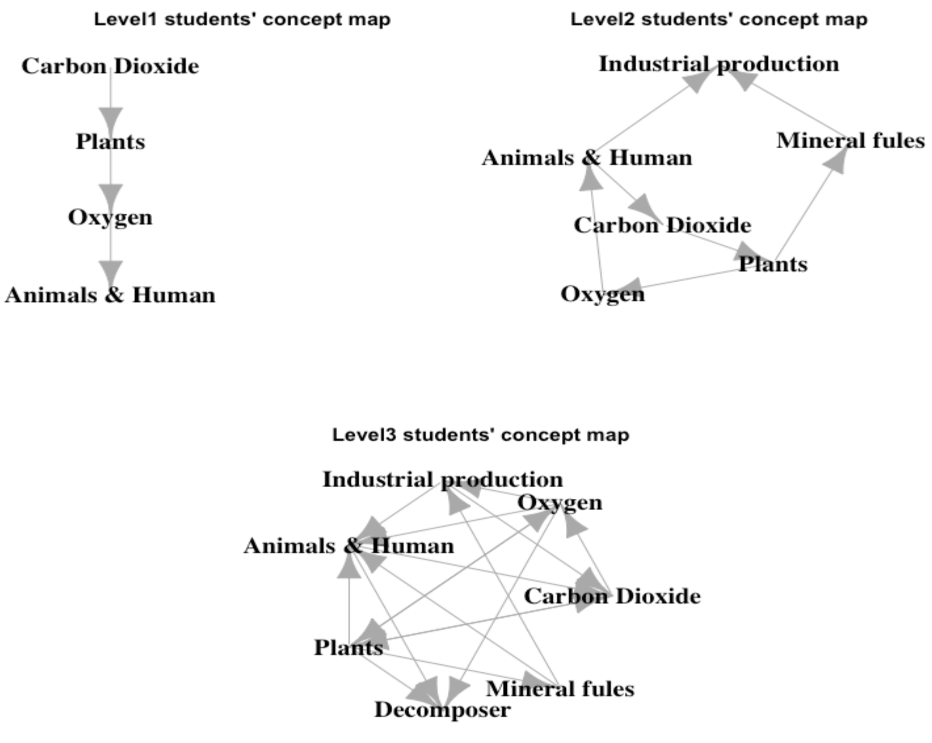
Although the students performed well in identifying the system components, analysis of the CMs indicated that most students possessed an incomplete picture of climate warming. Students' abilities to identify interrelations among components were assessed using the structural index (SX) of the CM (see Figure 3). The results of the CMs showed that most students' (82%) SX scores in Item 5 were less than .3 (Figure 3), indicating students' low ability to identify interrelations among system components. Figure 4 shows three typical networks that visualise the structure of the students' CMs at the three levels. The first network in Figure 4 indicates that students at Level 1 could not make connections among all concepts provided in the CM and tended to identify direct linear connections among concepts; 14.2% of students reached Level 2, and students at this level could make indirect relations among concepts (e.g. branches [at least two arrows lead to/away from a concept]) and identify a simple carbon cycle via plant photosynthesis and respiration of organisms in the second network of Figure 4. Only a few students (3.5%) connected all the concepts in a networked manner. Complex relationships (e.g., different cycles and interactions among oxygen, plants, and carbon dioxide) can be identified at Level 3 (Figures 3 and 4).

Figure 4
Examples of the Networks in Students' Concept Maps at the Three Levels



Ability to Analyse System Behaviour and System Characteristics

The results of Item 3 suggest that most students (54.1%) recognised dynamic changes among the three populations (wolves, deer, and plants), which help to maintain the equilibrium of the ecosystem. Furthermore, students' responses to Item 8 also support the result that most students (64.6%) were able to explain the disappearance of grey wolves, which caused an increase in the number of deer, which, in turn, damaged plants. However, students' inability to use emergent properties (e.g., carrying capacity and energy pyramid) to explain the changes in the ecosystem suggests that incomprehension of system characteristics hindered students' analysis of dynamic behaviours in the system. Item 3 showed that only a few students (4.4%) could explain the long-term changes in the number of animals based on the conception of the energy pyramid (Table 4).

Furthermore, the *t*-test analysis of Items 10 (*M* = .790) and 11 (*M* = 1.170) revealed that students performed significantly better in recognising the feedback loop than the nutrition cycle in the forest (t (2,147.7) = -8.92, $p <$ .001), and only 39% of students could correctly connect the process of the nutrition cycle in Item 10. These find-

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ings indicate that a lack of cyclic thinking makes it difficult for students to combine a variety of relationships into coherent cyclic and dynamic processes. Analysis of the CM also revealed a similar result; the third network in Figure 4 suggests that different carbon cycles exist in the context of climate warming (e.g., interactions via photosynthesis and the respiration of plants, cyclical processes such as plants' photosynthesis and the respiration of organisms, and the connection of mineral fuels to industrial emissions or human consumption). However, students at Levels 1 and 2 (56.2%) only formed a fragmented perception of the carbon cycle in the context of climate warming (Figure 4).

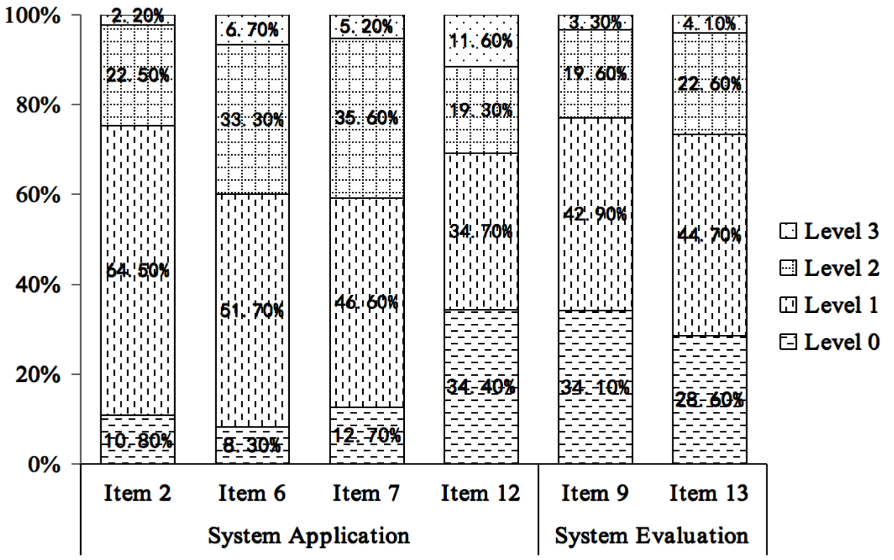
Table 4
Item 3 System Characteristics and Contents

System characteristics	Specific contents	Number of students
Direct/indirect interactions	The relations in food chains	254 (22.9%)
Dynamics and stability	Dynamic changes among populations	599 (54.1%)
Emergent property	Energy pyramid	49 (4.4%)

Ability to Make Predictions and Decisions

Figure 5 displays the proportion of student responses at different ST levels. The size of each chunk in the bar represents the proportion of the students. Figure 5 suggests that a large proportion of students' responses were at Level 1, which implies that monocausal and direct thinking dominated the students' systems application. Furthermore, students' preference to identify direct effects closely related to the environment also supports this result; see, for instance, the common responses in Item 2: 'Pollution of air and water caused the deaths of the organisms in the water'. Only a small proportion of students who formed a complex analysis at Level 3 (Figure 5) could anticipate the long-term effects based on a comprehensive understanding of the ecological, economic, and sociocultural dimensions of ecological issues (e.g., effects of industrial pollutants on residents' income in Item 2 and decision-making considering the sustainable development of the rainforest as well as the protection of local people's lifestyle in Item 12).

Figure 5
Students' Response Distribution Regarding the Items in System Application and System Evaluation



Note. Level 0 represents incorrect responses; Level 1 represents monocausal relations; Level 2 represents indirect/linear relations, and Level 3 represents complex relations.

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Ability to Make Evaluations about the Structures and Applications of Systems

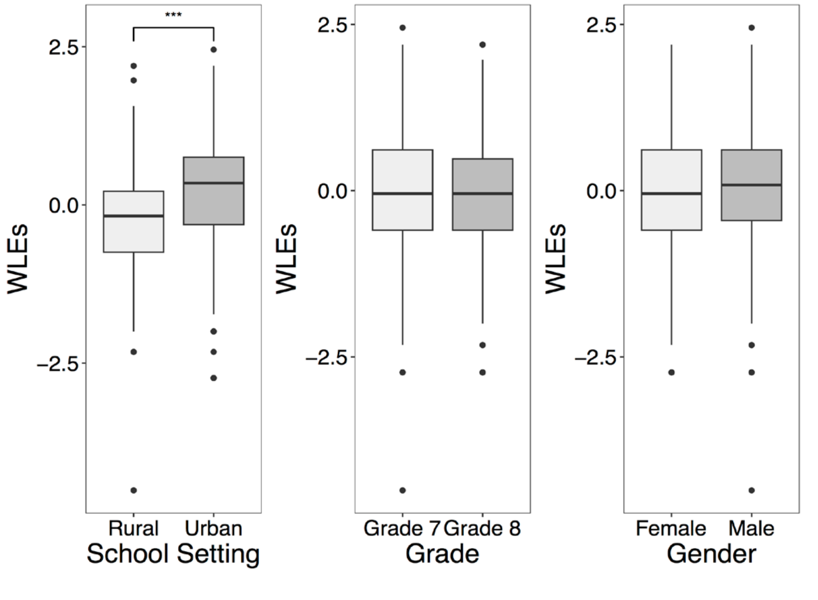
The results of Item 4 showed that holistic thinking was lacking in students' evaluation in that most students (84.3%) could find the error of isolated relations in the system, but few students (31.1%) could evaluate the relations from a system perspective. To make the right judgement about relation 9 ('human consumption of crop' is good for 'human health') in Item 4, students had to think about the whole system instead of just the parts, because the overuse of pesticides would result in crops accumulating pesticide residues. However, more than half of the students (53.2%) overlooked this whole system background. Furthermore, the results for Items 9 and 13 suggest that most students made evaluations in a monocausal (Level 1)/incorrect (Level 0) manner (Figure 5). Further analysis of students' responses indicated that these students lacked reflective consciousness about the limitations of predictions and decisions and could not make full evaluations of the validity of decisions and predictions in a time dimension; for example, they were unable to determine the long-term effects of killing grey wolves on ecosystems and that of a fishing ban on the economy and society.

Identification of Performance Gaps in Different Student Groups

The *t*-test was used to compare the means of student performances using WLEs for particular student groups (Figure 6). Students showed significantly different levels of performance based on their school location (t (1,090) = -8.388, p < .001); rural students (M = -.236) showed lower performance than urban students (M = .187). The results suggested that there was no significant difference between male (M = .033) and female students (M = -.049; t (1,090) = 1.583, p = .114), and no significant difference between Grades 7 (M = .01) and 8 (M = -.02) students (t (1,090) = .672, p = .502).

In the DIF analysis, Items 2, 5, 6, 7, and 9 appeared to be more difficult for rural school students, at a .01 significance level. The specific content and ST skills regarding these items were examined, and the analysis of students' responses indicated that rural students had more difficulties in identifying interactions among components and making predictions, decisions, and evaluations in an indirect or complex way than their urban counterparts. Furthermore, Items 5, 6, and 7 were all included under the context of climate warming, which means that this ecological issue is challenging for rural school students to understand.

Figure 6
Differences in ST Performance between Various Student Subgroups



Note. *** <. 001.

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Discussion

This study incorporates a broader set of ST skills (e.g., system decision-making and evaluation) for assessing students' consideration of diverse dimensions of ecological issues, resulting in a more comprehensive understanding of their ST performance in ecological issues. Furthermore, this study recruited a larger sample group than previous studies, thereby yielding more reliable and representative baseline data on lower-secondary school students' performance.

Regarding RQ1, the Wright map and the comparison of students' abilities both suggest that, on average, the students reached Level 1 of ST about ecological issues. The low ST performance of the participants is not surprising because some previous studies from different contexts also found similar results (Ben-Zvi Assaraf & Orion, 2005; Mambrey et al., 2020). Among the four skills in ST, systems organisation was found to be relatively easier for students, which is consistent with the findings of Evagorou et al. (2009) and Hmelo-Silver and Pfeffer (2004), who observed that the structure of a system was the most cognitively easy for students to understand.

The analysis of the students' responses to the items in RQ2 further explained the reasons for their low performance in understanding ecological issues. Students exhibited difficulties comprehending the interrelations among system components and identifying hidden elements in the ecosystem. The microorganism is invisible and thus easily neglected, making it difficult for students to identify them (Ben-Zvi Assaraf & Orion, 2005). Results in this study align with previous research findings that emergence is the most difficult system characteristic for students to understand (Hmelo-Silver et al., 2007; Jin et al., 2019; Sommer & Lücken, 2010). However, the analysis implies that stability and dynamics are relatively easy for the lower-secondary school students in China. The ecosystem equilibrium highlighted in the Chinese lower-secondary school biology curriculum likely promotes students' understanding of the characteristics. The little to no use of system concepts in explanations also supports the necessity of imparting general system characteristics (e.g., feedback loop, emergent properties, equilibrium) to scaffold students' coherent understanding of complex systems from a system perspective (Gilissen et al., 2020; Gilissen et al., 2021). Students lacked the cyclic perception, as reported by Ben-Zvi Assaraf et al. (2005) for the water cycle, and most students were unable to draw a complete network of interactions. The lack of time dimension hinders students' ability to make predictions and decisions based on long-term effects.

Although evaluation is an essential aspect of ST (Fanta et al., 2020; National Research Council, 2010), it is usually ignored in assessment. This study's findings indicate that students were less proficient in system decision-making and evaluation. There may be several reasons for this. First, the absence of reflective consciousness made it difficult for students to contemplate the limitation of prediction and decision. Second, the lack of holistic thinking prevented most of them from deciding or evaluating from a comprehensive perspective. The results also suggest students' inability to recognise other dimensions (such as social, economic, and cultural), and the indirect effects on ecological problems in their predictions, decision-making and evaluation. This further explains the dominance of monocausal reasoning in most students' ST, and their inability to fully understand the causes of ecological problems. This led them to decide and evaluate from a unidimensional perspective.

Regarding RQ3, this study's results contradict those of Jin et al. (2019), who concluded that the average performance of urban students was statistically significantly lower than that of rural students. A major reason for this is the contrast in urban area educational resources between China and the United States. Urban schools in the United States tend to have low resources, high teacher turnover, and low-quality students (Jin et al., 2019). However, with the accelerating urbanisation in China, resources have accumulated in urban areas. In general, urban schools in China have better educational resources and more highly qualified teachers than rural schools (Wen & Gu, 2017). Given that context-specific knowledge is necessary for developing ST (Ben-Zvi Assaraf & Orion, 2005; Sommer & Lücken, 2010), the lower performance of rural students in the context of global warming implies a possible lack of knowledge about this ecological issue. To explain the differences between rural and urban education more precisely, future research should explore the extent to which possible variables (e.g., socioeconomic status, teachers' teaching quality, and students' knowledge about ecological issues) influence students' ST.

Conclusions and Implications

This study explored lower-secondary school students' system thinking performance in ecological issues. The STTEI was administered for acquiring extensive data from Chinese students. Their overall ST performance was at Level 1, and an analysis of their responses revealed that they faced substantial difficulties in understanding ecological issues. Furthermore, this study is unique in revealing that most lower-secondary school students lack reflective

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consciousness, and are thus unable to consider the indirect impact of diverse dimensions, leading to monocausal reasoning in system application and evaluation. This study also found that Chinese rural students did not perform as well as their urban counterparts, specifically in the context of climate warming, which may be explained by rural school students' lack of the corresponding content knowledge.

These findings have significant implications, particularly for developing lower-secondary students' ST in ecological issues. First, teachers must address students' shortcomings, especially regarding emergent properties, cyclic perception, and interactions within complex systems. Second, ecological issues must be discussed from multiple perspectives for promoting ST in science classes and improving students' causal reasoning in complex systems. Third, there should be greater efforts in making rural students understand climate change. Future research must examine other variables for developing teaching strategies suited to students' backgrounds. Furthermore, qualitative methods (e.g., semi-interview) should be used for future assessments, so that the underlying causes of students' low performance are identified.

Declaration of Interest

The authors declare no competing interest.

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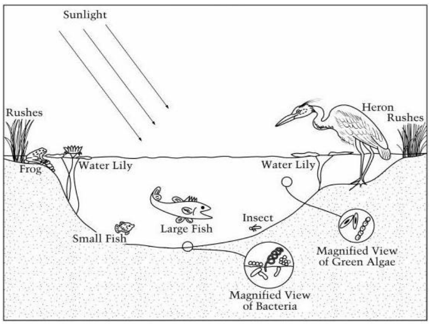
Appendix



Item 1 Answer the following questions based on the information provided in the picture:

Organisms that use the energy of sunlight to produce organic matter include______________.

Abiotic factors affecting the pond ecosystem include______________.

The decomposer in the pond is ______.

(Modified from the National Assessment of Educational Progress, http://nces.ed.gov/NATIONSREPORTCARD/)

Item 2 A newly built factory near the pond emits substantial amounts of sulphur dioxide and other pollutants and discharges wastewater containing heavy metal pollutants, nitrogen, and phosphorus (nitrogen and phosphorus will cause many green algae to multiply) into the pond. What do you think this will do to the creatures in the pond and the surrounding villagers?

Item 3 A remote island is uninhabited. The main animals on the island are wolves and deer, and the island is free from external interference all year round.

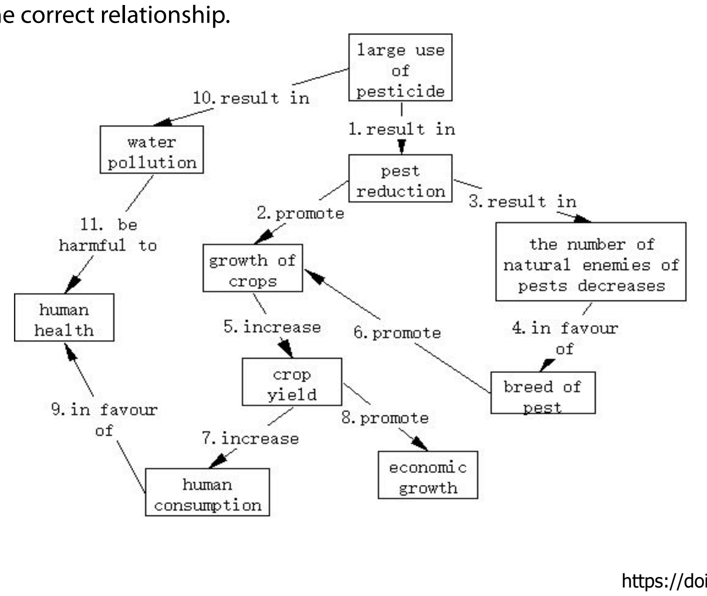
(1) Select the answer below that best describes what will happen to the average populations of the animals over time. （　　）

a) The deer will all die or be killed.
b) The wolves will all die.
c) There will be many more deer than wolves.
d) There will be many more wolves than deer.
e) The populations of each will be approximately equal.

(2) Choose the reason for your answer（　　）

a) Wolves prey on deer, and deer are eaten up by wolves.
b) Wolves prey on deer, causing the number of deer to decrease.
c) Wolves prey on deer. The number of deer decreases. Wolves die as they lack food.
d) To maintain the ecological balance of the 'plant → deer → wolf' food chain, the number of wolves and deer will fluctuate up and down within a certain range.
e) When energy is transmitted along the food chain, it decreases step by step. The population of wolves store less energy than the population of deer.

Item 4 The following concept map describes the impact of heavy use of pesticides in farmland on people and the ecosystem. There are two errors in the word relationships described in the concept map. Write the wrong serial number and explain the correct relationship.



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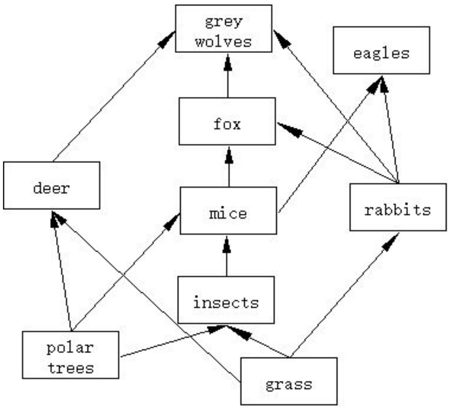
Item 6 Together with the concept map you have constructed, please predict what will happen if the number of plants substantially decreases.

Item 7 Everyone is responsible for protecting the Earth as our home. Please put forward specific measures to mitigate climate warming.

Please answer the following questions according to the information in the food web (the arrow in the food web points to the predator).



Item 8 If all grey wolves disappear, what will be the trend in the deer population ( )

A. It will keep growing.

B. It will grow first, then decrease.

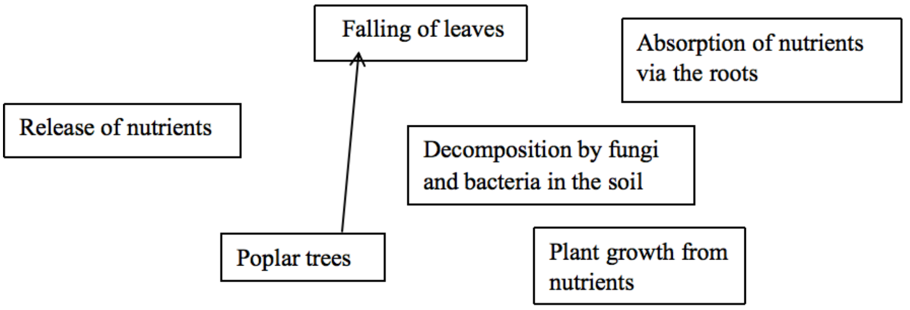
C. It will keep decreasing.

D. It will decrease first, then grow again.

Explain the reasons for your answer:

Item 9 To protect the safety of villagers near the forest, some people proposed to kill all the grey wolves in the forest, but Ming argued that 'if there are no grey wolves in the forest, the number of all herbivores in it will increase rapidly in a short period, thus damaging the stability of the ecosystem'. Do you think Ming's analysis is correct? Please explain your reasons.

Item 10 Use arrows to connect the following words to form the nutrient cycle of poplar trees in the forest. The first arrow has been provided in the picture, and the last arrow you draw must point to 'poplar trees'.



(Modified from Mehren et al., 2018)

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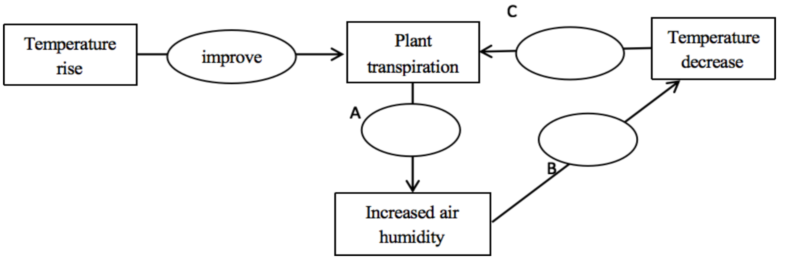
Item 11 Trees and plants can reduce ambient temperature through transpiration. The higher the ambient temperature, the stronger the transpiration of plants, and the more water in plants is emitted into the air. Please judge what changes will happen to the forest environment when the temperature rises and the transpiration of plants increases. Fill in 'promote' or 'weaken' at A, B, and C in the following figure (as shown in the example below). Please fill in the blanks in the order of A → B → C.



Item 12 The Khmus people in Xishuangbanna have been using slash-and-burn cultivation in the tropical rainforest. They cut down and burn trees to clear the land for planting food. The ashes from the burning of trees can increase soil fertility. This planting method is only effective for one year, and the land fertility will decline in the next year. The rainforest includes valuable trees (with high prices) and ordinary trees. After cutting them down, it takes at least ten years to recover the trees.

(1) To achieve sustainable development of tropical rain forests and the planting activities of Khmus, which of the following measures do you think is the most reasonable?

A. Cut down all the trees in the rainforest and sell the valuable trees.

B. Only cut down the valuable trees in the rainforest and sell all the valuable trees.

C. Divide the entire rainforest area into ten equal segments. Every year, cut down trees only in a partial area and sell the resulting valuable wood.

D. Divide the entire rainforest area into ten equal segments. Every year, cut down trees only in a partial area and sell all the resulting wood.

(2) Explain the reasons for your answer.

Item 13 Zhoushan in Zhejiang Province is known as the 'Eastern Fish Warehouse' in China. People here basically rely on fishing to make a living. However, with the overfishing of yellow croakers, the number of yellow croakers has declined sharply in the past few years. One reason is that many young yellow croakers have been caught. To prevent the extinction of wild yellow croakers, the measure of 'banning fishing within three years' was proposed. Do you think this measure is feasible? Please explain your reasons.

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GENDER DIFFERENCES IN EXPERIENCES OF 6TH-GRADE STUDENTS INQUIRY ACTIVITIES IN THE REPUBLIC OF KOREA

Soo-min Lim,
Youngshin Kim

Abstract. *Each student's individual experience in learning is very important. Lower secondary school students are engaged in activities that focus on inquiry rather than the acquisition of scientific knowledge in science classrooms. Therefore, the experiences and thoughts of lower secondary school students in the stage of scientific inquiry need to be analyzed. To this end, the internal and external experiences of students in the stages of observation, variable control, and conclusion drawing were analyzed through candle-burning experiments. Seventy-seven 6th-grade students were used as participants. The main activities; main actions; main thoughts; and contribution of actions, consciousness, and emotions were analyzed. No differences were observed in the external and internal experiences of male and female students in each stage of the inquiry activities. There were many cases in which other activities related to the inquiry were carried out in addition to the activities that were mainly performed at the corresponding stage. About 1/4 of the participants had internal experiences unrelated to inquiry. The results showed that interaction needs to be increased by including the variable control stage in the inquiry activities. Given that there were no differences in the external and internal experiences of male and female students, equal inquiry activities without gender discrimination can be achieved.*

Keywords: *internal experience, external experience, inquiry stage, gender difference.*

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Introduction

Individuals have various experiences, and depending on the way they construct and interpret the meaning of their experiences, they determine various future behavioral directions. The same goes for learning. In science education, it is the experience of learners directly participating in physical activities and thinking activities related to science and includes learners' emotions and subjective thoughts based on the experiences of classes or inquiry activities in the school curriculum (Choi & Choi, 2012). These experiences can play an important role in the formation of learners' scientific knowledge.

The most representative class in science class is inquiry activity. Inquiry activities are emphasized to encourage active participation and interaction among students in science classes (Nam et al., 2002). They are favored by students (Lim et al., 2021), but they are also a reason why students dislike science classes (Lee et al., 2007; Kim & Yang, 2005). In other words, the critical factor that determines success or failure in science education is inquiry activities (Kang et al., 2007). Small-group inquiry activity is one method for successfully completing inquiry activities. In this activity, students plan the process from designing experiments to drawing conclusions by interacting with other members and experience the problem-solving process by presenting, accepting, criticizing, modifying, and discussing opinions (Lumpe & Staver, 1995; Richmond & Striley, 1996).

Many studies have analyzed the effects (Gillies, 2008; Johnson & Johnson, 2003; Slavin, 2013; Stevens, 2003), role types (Maloney, 2007; Richmond & Striley, 1996), and interactions among students in small-group inquiry activities (Alexopoulou & Driver, 1996; Kim et al., 2017; Lim et al., 2020). However, these studies failed to analyze what kind of activities and actions, thoughts, consciousness, and emotions were experienced by students in each stage of the scientific inquiry activities.

Meanwhile, Problem-solving strategies or interactions in small-group inquiry activities vary depending on gender (Lim et al., 2020; Peltz, 1990), academic achievement, interest, and affective aspects (Alexopoulou & Driver, 1996; Yang et al., 1996; Yang et al. al., 2006). In particular, it is reported that there is a very clear gender difference in attitudes related to science (Park & Shin, 2011). These differences can have a negative impact on successful scientific inquiry activities. Therefore, a study on the causes of gender differences in small group inquiry activities is required.

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Students experience various events, interactions, activities, and thoughts at every moment during small-group inquiry activities. If an analysis is conducted on the interaction or experiences of each stage in the small group inquiry activity, that is, the activities and thoughts, it is possible to find the cause of the gender difference as well as the specific implications for the success of the small group inquiry activity. Therefore, it is necessary to analyze what kind of activities and actions, what kind of thoughts, and what kinds of consciousness and emotions are experienced in each stage of scientific inquiry activities. These experiences are mainly divided into external and internal experiences (Hektner et al., 2007). External experience refers to events experienced externally (Hektner et al., 2007), whereas internal experience refers to events experienced internally (Kim et al., 2005). The experience sampling method (ESM) is used to determine external and internal experiences.

ESM can analyze what kind of activities and emotions that participants feel under what circumstances at a specific time (Hektner et al., 2007). It has been used in various cultures for a long time and is recognized for its reliability and validity (Park & Choi, 2018). ESM can reduce memory bias because it immediately secures information at a specific moment and is suitable for analyzing various psychological changes that students experience. In particular, ESM needs to be applied when the participant is a student because it is difficult to maintain consistency in subjective judgment on cognition or emotion (Savin-Williams, 1987).

ESM is actively applied in psychology or empirical research for professional development. In the field of education, a previous study examined the link between the quality of a cooperative learning environment and the quality of students' experiences in subjects such as English, mathematics, science, and sociology (Shernoff et al., 2016). Another study analyzed the experiences of leaders and alienated students in inquiry activities (Choi et al., 2022). Therefore, it is useful to analyze the experience of general students according to gender.

In lower secondary school, emphasis is placed on improving the inquiry process rather than scientific knowledge (Haefner & Zembal-Saul, 2004), and many inquiry activities centered on observation or simple experiments are performed. The small-group science inquiry activities experienced by lower secondary school students during this period determine very diverse perceptions, such as their future jobs related to science and technology or their dislike for science (Kim & Shin, 2013). Therefore, it is required to have an interest in science and a correct perception of it in the lower secondary school age (Korean Association of Career Education, 2000), which is the stage in which students begin to recognize their career path. Therefore, it is meaningful to analyze the experiences that lower secondary school students experience in small-group science inquiry activities.

In this study, ESM was used to compare external and internal experiences according to gender in small-group science inquiry activities in lower secondary schools. External experiences were divided into the main activities and actions, and internal experiences were divided into thoughts, contributions of actions, consciousness, and emotions, and these were compared and analyzed according to gender groups. To this end, the differences between male and female students were analyzed by comparing the external and internal experiences experienced by both groups at each stage of scientific inquiry activities (observation, variable control, and conclusion drawing). Through this study, it will be possible to provide guidance for inquiry activities by identifying the behavior and thoughts of lower secondary school students in the inquiry stage.

Theoretical Background

Experiences

The daily life experienced by individuals, which consists of trivial things being repeated every day, has been taken for granted. However, from the beginning of emphasizing the specific reality and life of individuals in everyday life, experience has become the subject of academic research (Han & Son, 2009). Individuals, who are the subject of experience, experience various events and activities, and through these external activities, individual subjective evaluations are made at each moment, resulting in various internal experiences. These experiences are settled and accumulated in various forms in human memory. Experience is not simply linear, but it takes on a complex character that is influenced by previous experiences and also affects future experiences. Beyond this temporal sequence, it is reconstructed and reorganized.

Experience can be divided into external and internal experiences (Csikszentmihalyi, 1990). External experience means "an experience that one actually experiences or experiences externally." Internal experience can be defined as "an experience experienced internally in the mind or heart." The former is related to "where, with whom, and what we did," whereas the latter refers to psychological factors related to "what we felt and thought" in such activities.

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In the case of external experiences, previous studies usually classify into the type of activity (Lee & Choi, 2011), the people with whom they are together (Hnatiuk, 1991; Larson et. al, 1986; Lee & Choi, 2011), and the current place (Larson & Richards, 1994; Schneider & Waite, 2005). In the case of inquiry activities, since the current place is the same, the type of activity, and the people with whom they are together were used for classification. At this time, Kim et al. (2005), it was conducted by reflecting the characteristics of science inquiry activities.

On the other hand, although we have various external experiences, what actually determines our consciousness and behavior is the internal experience of how our emotions react when we do these actions (Csikszentmihalyi, 1990). Likewise, although external experiences are important, it can be said that an individual's internal experiences in the process of life are very meaningful to us (Fredrickson, 2009). Accordingly, the internal experience was categorized into what kind of thoughts were made during inquiry activities, whether one thought that one's actions contributed to inquiry activities (Csikszentmihalyi & Schneider, 2000), and what kind of consciousness and emotions were felt during inquiry activities (Shernoff et al., 2016).

Previous studies on experience classified quality of life into internal and external experiences (Kim & Kim, 2019; Lee, 2017) and analyzed students' class environment (Park, 2018; Cho & Kim, 2018). In science education, studies have analyzed the influence of science awareness and experience on career choice in science and technology (Lee, 2011) and conducted qualitative research on self-efficacy according to science teachers' experiences (Park, 2001). In addition, some studies have surveyed the impact of informal science experiences outside the classroom (Bell et al., 2009; Galen, 1993; Parker & Gerber, 2002) and science experiences through mentorship with experts in the field of science (Feldman, 2007; Koch & Appleton, 2007; Markowicz, 2004) on students' cognitive and affective aspects. However, these studies did not analyze students' actual experiences during scientific inquiry activities.

The Experience Sampling Methods

A person's behavior is what appears in the interaction with the situation (Oishi et al., 2004). ESM was developed by Csikszentmihalyi and Larson as an effective way to properly identify changes in human behavior depending on the situation. Several previous studies (Brandstatter, 1983; Flory et al., 2000; Oishi et al., 2004) revealed the complexity of the interaction between situations and humans, all of which used ESM. Since ESM requires immediate responses at random points in real life, it has the advantage of being able to analyze complex interactions of situations, behaviors, and emotions.

It is a psychometric method in which participants' actions are stopped at specific points and their experiences are recorded in real time. The ESM is classified into three types according to the response signal notification method: interval-contingent sampling, signal-contingent sampling, and event-contingent sampling (Reis, & Gable, 2000). Interval-contingent sampling is a method of responding at predetermined intervals. Signal-contingent sampling is a method of responding according to a randomly notified signal without fixing the timing. Although it can reduce the psychological distortion of the respondent, it has a problem of increasing the burden on the respondent. Event-contingent sampling is a method of responding when a predetermined event occurs. Event-contingent sampling is effective when analyzing events with a very low frequency of occurrence (Cho & Nam, 2005). Likewise, because participants' experiences are sampled multiple times, a reasonable understanding of the phenomena experienced by individuals can be obtained, and changes in participants' experiences can be observed over time (Stone et al., 1999). It is also a research method with very high ecological validity that immediately grasps what an individual feels and thinks on their own in a state where the intervention of the observer is minimized without resorting to reminiscence (Csikszentmihalyi & Larson, 1987). Therefore, in previous studies on ESM, the internal and external experiences experienced by general students (Choi et al., 2003; Csikszentmihalyi & Graef, 1980; Kim et al., 2005; Shernoff et al., 2016), gifted children (Choi & Choi, 2012), and adults (Han & Son, 2009) regarding small sample of a specific layer were measured in specific situations, and the resulting quality of life or emotions were analyzed. In other words, ESM records and analyzes the experience or emotion of the period presented by the researcher in a questionnaire distributed in advance to the subject (Hektner et al., 2007).

ESM compensates for the disadvantages of existing research methods, such as memory errors caused by recall, and allows the observer to directly record the behavior and emotions of subjects, preventing the involvement of the observer's subjectivity. In addition, as a method to effectively identify changes in human behavior according to various situations, ESM can analyze the complex interaction between situations, individual behavior, and emotions (Shin, 2010).

Experiential knowledge helps solve problems in new and uncertain situations by providing information about

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possible limitations in solving the problem, what to focus on, or what not to do (Kolodner, 1997). In this way, students' experiences can provide implications for teaching-learning strategies. In particular, by analyzing students' experiences in science inquiry activities, which are the most representative form of class in science subjects, it is possible to provide implications for the success of science inquiry activities and science learning. Therefore, it is very useful to measure the behaviors and emotions that students typically experience during scientific inquiry activities by ESM.

Research Methodology

Design

This study was conducted using a quantitative research design to answer the research question. The quantitative research design involves collecting quantitative statistical data on several variables studied to answer the research questions (Cohen & Manion, 1994; Creswell, 2003). This study is a quantitative research design that collects data using questionnaires.

The independent variable in this study was gender, and the dependent variables were external and internal experiences during inquiry activities. Quantitative data of this study were collected by modifying and supplementing the questionnaire developed by Kim et al. (2005) on external experience and the questionnaire developed by Csikszentmihalyi and Schneider (2000) and Shernoff et al. (2016) on internal experience.

The study was conducted from October to December 2018. The participants were students from three schools located in metropolitan cities and municipalities in the Republic of Korea and were sixth-grade lower secondary school students who were not gifted or special students.

Under the scope of this study, the participants were invited through the homeroom teacher at the lower secondary school. All of the participants and their parents agreed to participate voluntarily in the research. While collecting the data, the participants did not write their names and last names while responding to the items.

Participants

The participants of this study were 6th-grade students. Students from two schools located in a metropolitan city with a population of 2.5 million and one school located in a city with a population of 300,000 in the Republic of Korea were sampled. A total of 77 students (40 male and 37 female students) were sampled. Students who agreed on the purpose and method of the study were targeted, and the science achievement level of these students was moderate. By the central limit theorem, this study was conducted on the basis that quantitative verification is possible because if the sample for quantitative verification is large enough ($n>30$), independent, and sampled at random, it exhibits a normal distribution regardless of the distribution (Kwak & Kim, 2017).

Inquiry Programs

The program used in this study is a candle-burning experiment. In this inquiry activity, a candle is set in clay in a water tank, and a glass cup is placed over the candle. Students observe the rising water level in the glass as the candle goes out. Through observation, an inquiry problem is given, and an experiment is designed and conducted to solve the given inquiry problem. The reason for selecting this topic is that it is not covered in lower secondary schools in the Republic of Korea, so it is possible to conduct research activities without prior knowledge. The total time of the program was 100 min (40 min for the observation stage, 25 min for the variable control stage, 25 min for the conducting experiment stage, and 10 min for the conclusion drawing stage).

The stages of inquiry activity consist of observation, variable control, and conclusion drawing. In the observation stage, students directly observed the candle burning and described various observations. After the observation activity, the classroom teacher presented the research topic "the amount of water rising in the collector according to the number of candles." In the variable control stage, the experimental design was designed to verify the research topic presented through interaction among the group members. At this stage, the group members were asked to discuss with each other how to control the variables and carry out the experiment in detail. According to the experimental plan, each small group conducted the experiment, collected the data, converted the data, and drew conclusions based on the experimental results.

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Questionnaire

ESM was used to analyze external and internal experiences in scientific inquiry activities. The questionnaire surveys students' external and internal experiences in three stages: observation, variable control, and conclusion drawing.

The questionnaire consisted of the main activities and main actions as the external experience and the main thought and contribution of actions during the inquiry activities as the internal experience. For internal experience, questions about consciousness and emotions felt during inquiry activities were included. Table 1 presents the detailed composition of the questionnaire items.

Table 1
Composition of the Questionnaire

Experience	Item numbers	Contents	Item type
External experiences	1	Main activities	Closed-ended
	2	Main actions	Open-ended
Internal experiences	3	Main thoughts	Open-ended
	4	Contribution of actions	Open-ended
	5	Consciousness*	Likert scale
	6	Emotions*	Likert scale

*survey after the scientific activity

The items of the main activities and actions of external experience were based on the study by Kim et al. (2005) with some modifications. The main activities in the external experience were structured in closed-ended questions so that students could present and choose from listening to the teacher's words or directives, conducting the experiment with their peers, talking about the experiment, and personal behavior (Kim et al., 2005). The main actions were configured in open-ended questions so that the participant could record what kind of action and with whom it was conducted during the inquiry activity.

The main thoughts and contributions of the main actions of internal experience were constructed based on the form used by Csikszentmihalyi and Schneider (2000). Consciousness and emotion during inquiry activities were used by modifying the questionnaire by Shernoff et al. (2016). The main thought in the internal experience was made possible to present all of the thoughts that were in each stage of the inquiry activity and to present activities related and unrelated to the class. The contribution of actions made it possible to suggest whether the actions of the participant were helpful to the inquiry activity (Shernoff et al., 2016). In addition, in the internal experience, the consciousness and emotion felt during the inquiry activity were presented on a five-point scale.

Six experts were consulted to verify the validity of the test items. Among them, four had doctoral degrees in science education, and two were science teachers with master's degrees and more than 10 years of experience. The content validity of the item was 90.4%. The Cronbach's alpha and reliability of the questionnaire for consciousness and emotion were .939 and .872, respectively.

Analysis Framework

To analyze the open-ended items in the questionnaire, students' external and internal experiences were categorized into experimental activities (A), emotions (B), interactions (C), and others (D) sections based on the questionnaire's contents (Table 2). The experimental activities section (A) selected observation, measurement, variable control, result prediction, data transformation, and conclusion drawing in the basic inquiry and integrated inquiry among the inquiry process elements of the Test of Science Process Skills. Experiment preparation (A1) and conducting experiment (A2) were added because the activities of preparing and conducting experiments through interaction among students within a small group are important activities.

The emotion section (B) was classified into positive and negative emotions. Positive emotions are fun, enjoyable, exciting, interesting, surprising, and want to do more experiments, whereas negative emotions are futile, annoying, difficult, boring, and uninteresting.

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The interaction section (C) was classified into questions, responses, presentation of opinions, receiving opinions, behavioral participation, atmosphere, and responses to opinions (Lee et al, 2002). Experiences that were not included in the above classification and actions, thoughts, and non-responses that were not specifically related to inquiry activities were classified in the others section (D). The validity of the analysis framework was obtained by consulting five science education researchers, and a validity of 88% was obtained.

Table 2
Framework for Analysis

Experimental activities (A)	Experiment preparation(A1), conducting experiment (A2), observation(A3), measurement(A4), variable control(A5), result prediction(A6), data transformation(A7), data interpretation(A8), conclusion drawing(A9)
Emotions (B)	Positive emotion(B1), negative emotion(B2)
Interactions (C)	Question(C1), response(C2), presentation of opinions(C3), receiving opinions(C4), behavioral participation(C5), atmosphere(C6), responses to opinions(C7)
Others (D)	Non-response, actions, and thoughts not related to inquiry activities (e.g., personal action, small talk, thinking about games, thinking about break time, etc.)

Data Collection and Analysis

People's experiences emerge through their interactions with situations (Oishi et al., 2004). In other words, students' experiences emerge in the interaction with the situation of inquiry activities. In order to collect various internal and external experiences experienced by students, the small group was randomly composed of five members. According to Lim et al. (2019), the most diverse forms of interaction appear in a small group consisting of five members, it was assumed that various internal and external experiences could be collected. According to the science block time, the science inquiry activities took three classes, each lasting 40 minutes. At this time, event-contingent sampling, which is the most efficient way to sample students' experiences in the special situation of scientific inquiry, was used (Cho & Nam, 2005). In the Republic of Korea, most participants in lower secondary schools, including science, are taught by homeroom teachers. Lower secondary school education in the Republic of Korea is centered on the class, and the homeroom teacher is responsible for managing each class. Homeroom teachers in lower secondary schools, guide students in subject learning, help them adjust to society, provide evaluation and feedback, and provide guidance and counseling on life attitudes. This inquiry activity program was also conducted by the homeroom teacher. Before the inquiry activity program was conducted, the homeroom teacher held a seminar and practiced on the program treatment process in advance.

When each step of the inquiry activity was completed, an alarm was sounded, and each step-by-step questionnaire was answered for 10 min. Among the questionnaires collected from the students, closed-ended items were analyzed based on frequency analysis, and open-ended items (item 2 to item 5) were analyzed based on the analysis framework (Table 2). Four doctors of science education used the analyzed data to determine agreement, and 92% agreement was obtained among them.

The collected data were quantitatively analyzed using SPSS 25.0. The open-ended items were analyzed in a classification frame, followed by descriptive statistics, and the χ^2 test was used to compare male and female students in each stage of the inquiry activity. In the case of the five-point Likert scale items, differences were compared and analyzed through descriptive statistics and independent sample *t*-test. In the case of negative items, analysis was performed through reverse scoring.

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Research Results

External Experience

Main Activities

The external experience in the inquiry activity stage was largely classified into main activities and main actions. Table 3 shows the main activities that students performed in the stages of observation, variable control, and conclusion drawing among scientific inquiry activities. This allows for multiple responses.

Table 3
External Experience regarding the Main Activity at Each Stage of Inquiry

	Observation: *n*(%)			Variable control: *n*(%)			Conclusion drawing: *n*(%)		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Listening to the teacher's directives	12 (21.4)	14 (22.2)	26 (21.8)	12 (21.1)	12 (22.2)	24 (21.6)	11 (18.0)	10 (17.2)	21 (17.6)
Experiment with peers	29 (51.8)	30 (47.6)	59 (49.6)	21 (36.8)	14 (25.9)	35 (31.5)	29 (47.5)	25 (43.1)	54 (45.4)
Conversation with peers about experiments	12 (21.4)	17 (27.0)	29 (24.4)	18 (31.6)	20 (37.0)	38 (34.2)	16 (26.2)	17 (29.3)	33 (27.7)
Personal action	3 (5.4)	0 (0.0)	3 (2.5)	4 (7.0)	2 (3.7)	6 (5.4)	3 (4.9)	3 (5.2)	6 (5.0)
Others	0 (0.0)	2 (3.2)	2 (1.7)	2 (3.5)	6 (11.1)	8 (7.2)	2 (3.3)	3 (5.2)	5 (4.2)
Total	56 (100.0)	63 (100.0)	119 (100.0)	57 (100.0)	54 (100.0)	111 (100.0)	61 (100.0)	58 (100.0)	119 (100.0)

Experiments with peers (49.6%) was the main activity performed by students in the observation stage, followed by conversation with peers about experiments (24.4%) and listening to the teacher's directives (21.8%). Conversation with peers about experiments (34.2%), experiments with peers (21.4%), and listening to the teacher's directives (21.6%) were the main activities in the variable control stage. Meanwhile, experiments with peers (45.4%), conversation with peers about experiments (27.7%), and listening to the teacher's directives (21.6%) were the main activities in the conclusion drawing stage.

The following gender differences were observed in each stage of the inquiry activity. For male students, experiments with peers was the main activity in the observation stage, followed by listening to the teacher's directives and conversation with peers about experiments (both having the same frequency). For female students, experiments with peers was the main activity, followed by conversation with peers about experiments and listening to the teacher's directives. As such, experiments with peers showed the highest frequency regardless of gender in the observation stage. In the variable control stage, experiments with peers was the main activity for male students, followed by conversation with peers about experiments and listening to the teacher's directives. For female students, conversation with peers about experiments was the main activity, followed by experiments with peers and listening to the teacher's directives. In the conclusion drawing stage, experiments with peers was the main activity for male and female students, followed by conversation with peers about experiments and listening to the teacher's directives.

The results showed that experiments with peers was the main action performed in most inquiry activity stages. However, conversation with peers about experiments had a higher frequency for both genders in the variable control stage compared with other stages. During the inquiry activities, students mostly conducted experiments with peers, conversed with peers about experiments, and listened to the teacher's directives. However, the frequency of conversation with peers about experiments was relatively higher in the variable control stage compared with other stages. This is expected to be more active among students in the variable control stage, in relation to a previous study (Choi et al., 2022) that reported that verbal interactions occur more actively in the variable control stage than in other stages.

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Main Actions

The main actions performed by lower secondary school students in each stage of the science inquiry activities are as follows (Table 4). In the experimental activity section (A) during the observation stage, the students' main activities were conducting experiments or observing. In the emotion section (B), only positive emotions appeared. In the interaction section (C), behavioral participation (C5), presentation of opinions (C3), and behavior related to the atmosphere (C6) were in that order.

In the experimental activity section (A) during the variable control stage, students usually prepared experiments or control variables as their main actions. In the emotion section (B), only negative emotion (B2) appeared unlike that in the observation stage. In the interaction section (C), the presentation of opinions (C3) and receiving opinions (C4) had the highest frequency. In the variable control stage, the frequency of behavior related to interaction was higher than that in other stages. In particular, there were many practical verbal interactions in which opinions were exchanged on inquiry activities.

In the conclusion drawing stage, most actions were related to the experimental activity section (A), followed by actions related to the interaction section (C) and actions related to the emotion section (B).

Table 4
Main Actions of External Experiences at Each Stage of Inquiry

Sections		Observation: *n(%)*			Variable control: *n(%)*			Conclusion drawing: *n(%)*		
		Male	Female	χ^2	Male	Female	χ^2	Male	Female	χ^2
Experimental activities (A)	A1	1(1.1)	1(0.9)	3.345	19(21.6)	15(14.4)	1.113	7(9.3)	4(4.6)	3.650
	A2	31(35.6)	30(28.3)		3(3.4)	5(4.8)		29(38.7)	28(32.2)	
	A3	14(16.1)	15(14.2)		0(0.0)	0(0.0)		8(10.7)	9(10.3)	
	A4	2(2.3)	1(0.9)		0(0.0)	0(0.0)		7(9.3)	6(6.9)	
	A5	0(0.0)	0(0.0)		13(14.8)	11(10.6)		1(1.3)	1(1.1)	
	A6	0(0.0)	3(2.8)		5(5.7)	6(5.8)		1(1.3)	0(0.0)	
	A7	0(0.0)	0(0.0)		0(0.0)	0(0.0)		0(0.0)	1(1.1)	
	A8	0(0.0)	0(0.0)		0(0.0)	0(0.0)		1(1.3)	1(1.1)	
	A9	0(0.0)	0(0.0)		0(0.0)	0(0.0)		3(4.0)	1(1.1)	
	sub-total	48(55.2)	50(47.2)		40(45.5)	37(35.6)		57(76.0)	51(58.6)	
Emotions (B)	B1	2(2.3)	3(2.8)	.000	0(0.0)	0(0.0)	.000	1(1.3)	2(2.3)	.444
	B2	0(0.0)	0(0.0)		0(0.0)	3(2.9)		0(0.0)	1(1.1)	
	sub-total	2(2.3)	3(2.8)		0(0.0)	3(2.9)		1(1.3)	3(3.4)	
Interactions (C)	C1	0(0.0)	2(1.9)	7.486	0(0.0)	2(1.9)	4.655	0(0.0)	0(0.0)	1.415
	C2	0(0.0)	0(0.0)		0(0.0)	0(0.0)		0(0.0)	0(0.0)	
	C3	4(4.6)	13(12.3)		16(18.2)	22(21.2)		2(2.7)	7(8.0)	
	C4	2(2.3)	7((6.6)		17(19.3)	21(20.2)		2(2.7)	5(5.7)	
	C5	20(23.0)	18(17.0)		4(4.5)	7(6.7)		6(8.0)	13(14.9)	
	C6	7(8.0)	7(6.6)		2(2.3)	7(6.7)		3(4.0)	5(5.7)	
	C7	3(3.4)	5(4.7)		4(4.5)	2(1.9)		3(4.0)	3(3.4)	
	sub-total	36(41.4)	52(49.1)		43(48.9)	61(58.7)		16(21.3)	33(37.9)	
Others (D)		1(1.1)	1(0.9)	_	5(5.7)	3(2.9)	_	1(1.3)	0(0.0)	_
Total		87 (100.0)	106 (100.0)	–	88 (100.0)	104 (100.0)	–	75 (100.0)	87 (100.0)	–

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In the observation stage, actions related to experimental activities had the highest frequency for male students, followed by actions related to interactions and actions related to emotions. On the other hand, actions related to interaction had the highest frequency for female students, followed by actions related to experimental activities and actions related to emotion. In the observation stage, actions related to experimental activities and interactions had the highest frequency regardless of gender. Specifically, male and female students conducted experiments and observations in relation to experimental activities. In the interaction section, actions related to behavioral participation had a high frequency regardless of gender. There was no difference in the main actions of external experiences at the observation stage of inquiry by gender (p>.05): In the experimental activities section (χ^2 = 3.345, df = 8, p = .911), interactions section (χ^2 = 7.486, df = 6, p = .278), and emotions section (χ^2 = .000, df = 1, p =1.000).

In the variable control stage, actions related to interaction had the highest frequency regardless of gender, followed by the actions related to the experimental activities section (A). Specifically, actions related to presenting opinions and receiving opinions had a high frequency regardless of gender. The actions related to the experimental activities section, experiment preparation and variable control activities were mainly performed. In this way, there was no difference in the main actions of external experiences at the variable control stage of inquiry by gender (p>.05): In the experimental activities section (χ^2 = 1.113, df = 8, p = .997), interactions section (χ^2 = 4.655, df = 6, p = .589), and emotions section (χ^2 = .000, df = 1, p =1.000).

In the conclusion drawing stage, actions related to the experimental activities section (A) had the highest frequency regardless of gender, followed by actions related to interaction and emotion section (B). Moreover, actions related to the experimental activities section (A) had a higher frequency in the conclusion drawing stage compared with other stages, confirming that actions related to interactions had a low frequency. On the other hand, it was confirmed that students did not perform activities related to conclusion drawing, such as conducting experiments or conducting observations, in the conclusion drawing stage. In this way, there was no difference in the main actions of external experiences at the conclusion drawing stage of inquiry by gender (p>.05): In the experimental activities section (χ^2 = 3.650, df = 8, p = .887), interactions section (χ^2 = 1.415, df = 6, p = .965), and emotions section (χ^2 = .444, df = 1, p =.505).

In the observation and conclusion drawing stages, actions related to the experimental activities section (A) had the highest frequency. However, in the variable control stage, actions related to interactions had the highest frequency. In the variable control stage, verbal interaction was found to facilitate the exchange of opinions. This result proves that the variable control stage does not need to be focused on increasing student interaction. However, negative emotions were most often felt in the variable control stage. This showed that the student was relatively intimidated or felt difficulties through verbal interaction. Thus, students should be provided with emotional support.

Internal Experience

Main Thought

To analyze the internal experience of lower secondary school students, their main thoughts were presented at each stage of inquiry. The students' responses were classified into experimental activities, emotions, interactions, and other sections (Table 5). In the observation stage, thoughts related to interaction had the highest frequency appearing 78 times (43.8%), followed by others (48 times, 27.0%), experimental activities (38 times, 21.3%), and emotions related to experimental activities (14 times, 7.9%). In terms of gender, male and female students thought about interaction the most, followed by thoughts related to others, experimental activities, and emotion sections. Specifically, in the interaction section of the observation stage, thoughts related to question (C1) had the highest frequency. Meanwhile, in the experimental activities section, thoughts about result prediction (A6) had the highest frequency. However, there was no statistically significant difference by gender at the observation stage (p > .05): experimental activities (χ^2 = 3.638, df = 8, p = .888), interactions (χ^2 = 4.570, df = 6, p = .600), and emotions (χ^2 = .207, df = 1, p =.649).

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Table 5
Main Thoughts of Internal Experience at Each Stage of Inquiry

Sections		Observation: *n(%)*			Variable control: *n(%)*			Conclusion drawing: *n(%)*		
		Male	Female	χ^2	Male	Female	χ^2	Male	Female	χ^2
Experimental activities (A)	A1	2(2.2)	0(0.0)	3.638	6(6.6)	7(6.7)	3.853	0(0.0)	3(3.5)	10.413
	A2	4(4.5)	4(4.5)		1(1.1)	4(3.8)		7(9.6)	5(5.9)	
	A3	4(4.5)	6(6.7)		0(0.0)	0(0.0)		2(2.7)	2(2.4)	
	A4	1(1.1)	2(2.2)		0(0.0)	0(0.0)		0(0.0)	0(0.0)	
	A5	0(0.0)	0(0.0)		6(6.6)	13(12.5)		0(0.0)	2(2.4)	
	A6	6(6.7)	8(9.0)		16(17.6)	13(12.5)		5(6.8)	17(20.0)	
	A7	0(0.0)	0(0.0)		0(0.0)	0(0.0)		1(1.4)	0(0.0)	
	A8	0(0.0)	0(0.0)		0(0.0)	0(0.0)		2(2.7)	1(1.2)	
	A9	0(0.0)	1(1.1)		0(0.0)	0(0.0)		0(0.0)	0(0.0)	
	sub-total	17(19.1)	21(23.6)		29(31.9)	37(35.6)		17(23.3)	30(35.3)	
Emotions (B)	B1	4(4.5)	8(9.0)	.207	3(3.3)	4(3.8)	.298	6(8.2)	8(9.4)	.209
	B2	1(1.1)	1(1.1)		3(3.3)	7(6.7)		3(4.1)	6(7.1)	
	sub-total	5(5.6)	9(10.1)		6(6.6)	11(10.6)		9(12.3)	14(16.5)	
Interactions (C)	C1	27(30.3)	25(28.1)	4.570	17(18.7)	13(12.5)	4.624	18(24.7)	6(7.1)	9.560
	C2	3(3.4)	2(2.2)		0(0.0)	0(0.0)		0(0.0)	0(0.0)	
	C3	3(3.4)	2(2.2)		7(7.7)	5(4.8)		3(4.1)	2(2.4)	
	C4	1(1.1)	1(1.1)		3(3.3)	3(2.9)		0(0.0)	2(2.4)	
	C5	2(2.2)	2(2.2)		1(1.1)	5(4.8)		1(1.4)	3(3.5)	
	C6	2(2.2)	5(5.6)		5(5.5)	6(5.8)		3(4.1)	6(7.1)	
	C7	3(3.4)	0(0.0)		0(0.0)	1(1.0)		0(0.0)	0(0.0)	
	sub-total	41(46.1)	37(41.6)		33(36.3)	33(31.7)		25(34.2)	19(22.4)	
Others (D)		26(29.2)	22(24.7)	_	23(25.3)	23(22.1)	_	22(30.1)	22(25.9)	_
Total		89 (100.0)	89 (100.0)		91 (100.0)	104 (100.0)		73 (100.0)	85 (100.0)	

In the variable control stage, thoughts related to experimental activities and interaction sections had the highest frequency. For male students, interaction was higher than experimental activity, but for female students, experimental activity was higher than interaction. However, there were no statistically significant differences in experimental activities (χ^2 = 3.853, *df* = 8, *p* = .870), interactions (χ^2 = 4.624, *df* = 6, *p* = .593), and emotions (χ^2 = .298, *df* = 1, *p* =.585).

In the conclusion drawing stage, students mainly thought about the experimental activities section, followed by the interaction, others, and emotions sections. In terms of gender, male students thought about the interaction section the most, whereas female students thought about the experimental activities section the most. Specifically, in the experimental activities section, conducting an experiment (A2) had the highest frequency for male students, followed by result prediction (A6). By contrast, result prediction (A6) had the highest frequency for female students. In the interaction section, male and female students thought about question (C1) the most. However, there was no statistically significant difference by gender at the conclusion drawing stage (*p*>.05): experimental activities (χ^2 = 10.413, *df* = 8, *p* = .237), interactions (χ^2 = 9.560, *df* = 6, *p* = .144), and emotions (χ^2 = .209, *df* = 1, *p* =.648).

In the stage of inquiry activity, students thought about the experimental activities or interaction section the

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most and the emotions section the least. There was a slight difference in the order of the frequency of main thoughts according to gender at each stage of inquiry activity, but there was no statistically significant difference (p>.05). In addition, it can be confirmed that lower secondary school students have thoughts unrelated to class considering the high frequency of the others section. This can be related to a previous study (Kwak et al., 2020) showing that concentration on class is lowered when there is no positive experience, which is a defining achievement in inquiry activities. Therefore, it is necessary to create an atmosphere in which lower secondary school students can enjoy inquiry so that they can be interested and focus on class and improve science positive experiences.

Contribution of Actions

The students' responses to whether their actions during small-group science inquiry activities were helpful are as follows (Table 6). Most of the students thought that their actions helped their inquiry activities in all stages. However, 8 students in the observation stage, 13 students in the variable control stage, and 11 students in the conclusion drawing stage thought that their actions were not helpful to the inquiry activities.

Table 6
Contribution of Actions of Internal Experience at Each Step of Inquiry

	Observation: n(%)			Variable control: n(%)			Conclusion drawing: n(%)		
	Male	Female	χ^2	Male	Female	χ^2	Male	Female	χ^2
Yes	36(0.9)	33(89.2)	.136	33(82.5)	31(83.8)	.023	33(82.5)	33(89.2)	.702
No	4(0.1)	4(10.8)		7(17.5)	6(16.2)		7(17.5)	4(10.8)	
Total	40(100.0)	37(100.0)		40(100.0)	37(100.0)		40(100.0)	37(100.0)	

Male and female students mostly thought that their actions were helpful in all stages of the experimental activities. However, among male students, 4 students in the observation stage and 7 students in the variable control and conclusion drawing stages thought that their actions were not helpful in the inquiry activities. In the case of female students, 4 students in the observation and conclusion drawing stages and 6 students in the variable control stage thought that their actions were not helpful to the inquiry activities. The contribution of actions for inquiry activities by gender is as follows: observation stage (χ^2 = .136, p = .907), variable control stage (χ^2 = .023, p = .881), and conclusion drawing stage (χ^2 = .702, p =.402). There was no significant difference according to gender (p>.05).

On the other hand, the results of reasons for the contribution of actions by students in inquiry activities are as follows (Table 7). Overall, regarding the reasons for responding that inquiry activities were helpful, the interactions section (54.3%) had the highest frequency, followed by experimental activities (36.4%) and emotions (8.7%) sections. Specifically, in the observation stage, the interactions section had the highest frequency, followed by the experimental activities and emotions sections. In the interactions section, behavioral participation (C5) and presentation of opinions (C3) had the highest frequency. In the experimental activities section, conducting experiments (A2) had the highest frequency. In the variable control stage, interaction had the highest frequency, followed by inquiry activities and emotions. Behavioral participation (C5), presentation of opinions (C3), and atmosphere (C6) had a higher frequency in the interaction section than in other inquiry activity stages. In the experimental activities section, experiment preparation (A1) and variable control (A5) had the highest frequency. In the conclusion drawing stage, interactions (54.4%) had the highest frequency, followed by inquiry activities (39.4%) and emotions (5.3%). Similar to other stages, behavioral participation (C5) and presentation of opinions (C3) had high frequency in the interactions section. Conducting experiments (A2) was presented most frequently in the experimental activities section.

At each stage of the inquiry activity, students presented the reasons why their behavior contributed to the inquiry activity in the order of interactions, experimental activities, and emotions. However, the interaction was higher in the variable control stage than in the other stages. In the observation stage, more students responded to emotions (i.e., positive emotions) than in other stages. In the observation, variable control, and conclusion drawing stages, interactions had the highest frequency for males and females, followed by experimental activities and

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emotions. There was no statistically significant difference according to gender ($p > .05$). In the observation stage, it was experimental activities ($\chi^2 = 3.753$, $df = 8$, $p = .879$), interactions ($\chi^2 = 2.545$, $df = 6$, $p = .863$), and emotions ($\chi^2 = .000$, $df = 1$, $p = 1.000$). In the variable stage it was experimental activities ($\chi^2 = 3.200$, $df = 8$, $p = .921$), interactions ($\chi^2 = 1.735$, $df = 6$, $p = .942$), and emotions ($\chi^2 = .000$, $df = 1$, $p = 1.000$). And in the conclusion drawing stage, it was experimental activities ($\chi^2 = 3.346$, df = 8, $p = .911$), interactions ($\chi^2 = 2.811$, $df = 6$, $p = .832$), and emotions ($\chi^2 = .000$, $df = 1$, $p = 1.000$).

Table 7
Gender Differences in Reasons for the Contribution of Actions

Sections		Observation: *n(%)*			Variable control: *n(%)*			Conclusion drawing: *n(%)*		
		Male	Female	χ^2	Male	Female	χ^2	Male	Female	χ^2
Experimental activities (A)	A1	1(1.6)	1(1.8)	3.753	10(16.4)	4(7.4)	3.200	2(3.7)	3(5.0)	3.346
	A2	17(27.4)	13(23.6)		1(1.6)	2(3.7)		7(13.0)	11(18.3)	
	A3	2(3.2)	2(3.6)		0(0.0)	0(0.0)		2(3.7)	2(3.3)	
	A4	1(1.6)	1(1.8)		0(0.0)	0(0.0)		2(3.7)	3(5.0)	
	A5	1(1.6)	0(0.0)		9(14.8)	5(9.3)		0(0.0)	2(3.3)	
	A6	2(3.2)	0(0.0)		3(4.9)	3(5.6)		0(0.0)	2(3.3)	
	A7	0(0.0)	0(0.0)		0(0.0)	0(0.0)		0(0.0)	1(1.7)	
	A8	0(0.0)	0(0.0)		0(0.0)	0(0.0)		1(1.9)	2(3.3)	
	A9	0(0.0)	1(1.8)		2(3.3)	0(0.0)		2(3.7)	3(5.0)	
	sub-total	24(38.7)	18(32.7)		25(41.0)	14(25.9)		16(29.6)	29(48.3)	
Emotions (B)	B1	11(17.7)	9(16.4)	.000	0(0.0)	4(7.4)	.000	5(9.3)	1(1.7)	.000
	B2	0(0.0)	0(0.0)		0(0.0)	0(0.0)		0(0.0)	0(0.0)	
	sub-total	11(17.7)	9(16.4)		0(0.0)	4(7.4)		5(9.3)	1(1.7)	
Interactions (C)	C1	0(0.0)	0(0.0)	2.545	0(0.0)	0(0.0)	1.735	0(0.0)	0(0.0)	2.811
	C2	1(1.6)	1(1.8)		0(0.0)	1(1.9)		4(7.4)	2(3.3)	
	C3	6(9.7)	8(14.5)		11(18.0)	10(18.5)		5(9.3)	4(6.7)	
	C4	0(0.0)	2(3.6)		2(3.3)	4(7.4)		0(0.0)	0(0.0)	
	C5	16(25.8)	14(25.5)		15(24.6)	14(25.9)		20(37.0)	22(36.7)	
	C6	4(6.5)	3(5.5)		6(9.8)	6(11.1)		3(5.6)	1(1.7)	
	C7	0(0.0)	0(0.0)		1(1.6)	1(1.9)		0(0.0)	1(1.7)	
	sub-total	27(43.5)	28(50.9)		35(57.4)	36(66.7)		32(59.3)	30(50.0)	
Others (D)		0(0.0)	0(0.0)	_	1(1.6)	0(0.0)	_	1(1.9)	0(0.0)	_
Total		62 (100.0)	55 (100.0)	–	61 (100.0)	54 (100.0)	–	54 (100.0)	60 (100.0)	–

Consciousness and Emotions

Gender differences in consciousness and emotion felt by lower secondary school students during each inquiry activity were analyzed (Table 8). Male students showed the highest score in "concentration" (4.18), followed by "teacher's guidance" (4.15), "help" (4.10), "interest" (4.08), and "effort" and "learning" (4.03). On the other hand, female students showed the highest score in "effort" and "teacher's guidance" (4.19), followed by "concentration"

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(4.05), "interest" (3.89), and "help" (3.86). For male and female students, "teacher's guidance," "interest," and "help" corresponded to the main consciousness felt during inquiry activities.

Table 8
Consciousness of Internal Experience during Inquiry Activities

Consciousness	Group	*N*	*M*	*SD*	*t*	*p*
Opportunity to choose	Male	40	3.83	.81	.347	.357
	Female	37	3.76	.52		
Importance	Male	40	3.80	.57	.354	.362
	Female	37	3.73	.92		
Interest	Male	40	4.08	.84	.838	.202
	Female	37	3.89	.99		
Difficulty*	Male	40	3.43	1.38	−.141	.444
	Female	37	3.46	.92		
Enjoyment	Male	40	3.85	1.00	.677	.250
	Female	37	3.70	.83		
Concentration	Male	40	4.18	.51	.675	.251
	Female	37	4.05	.72		
High skill	Male	40	3.30	.68	.638	.263
	Female	37	3.19	.49		
Think of something else*	Male	40	3.00	1.59	1.645	.052
	Female	37	2.57	1.09		
Goal	Male	40	3.85	.59	1.018	.156
	Female	37	3.65	.90		
Effort	Male	40	4.03	.69	−.877	.192
	Female	37	4.19	.66		
Teacher's guidance	Male	40	4.15	.59	−.222	.412
	Female	37	4.19	.60		
Fit together	Male	40	3.90	.86	.406	.343
	Female	37	3.81	1.00		
Reflection of ideas	Male	40	3.68	.84	.122	.452
	Female	37	3.65	.96		
Learning	Male	40	4.03	.69	.929	.178
	Female	37	3.84	.86		
Help	Male	40	4.10	.71	1.148	.127
	Female	37	3.86	.90		
Total	Male	40	3.81	.95	.800	.215
	Female	37	3.70	.98		

*negative item

The mean for consciousness during inquiry activities was 3.81 for male students and 3.70 for female students, and there was no statistically significant difference between male and female students ($p > .05$). As such, the present study found no statistically significant difference regarding the specific consciousness for each item between male and female students.

Table 9 shows the gender differences in emotion during inquiry activities. Emotion was measured using a

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Likert scale using contrasting adjectives to express feelings or emotional states during the inquiry process. Male students felt "successful" the most with a score of 4.40, followed by "anxious" and "competitive" (4.36), "annoying" (4.32), and "pressured" (4.24). On the other hand, female students felt "annoying" and "competing" the most with a score of 4.26, followed by "anxiety" (4.12) and "pressured" (4.06).

Table 9
Emotions of Internal Experience during Inquiry Activities

Emotions	Group	*N*	*M*	*SD*	*t*	*p*
Joyful	Male	40	3.35	1.07	−.116	.454
	Female	37	3.38	1.46		
Creative	Male	40	3.84	.81	.573	.284
	Female	37	3.71	1.06		
Pressured*	Male	40	4.27	.93	.915	.182
	Female	37	4.06	.97		
Interesting	Male	40	3.87	1.01	1.297	.100
	Female	37	3.53	1.35		
Boring*	Male	40	3.92	.85	1.555	.062
	Female	37	3.53	1.35		
Anxious*	Male	40	4.35	.90	.905	.184
	Female	37	4.12	1.44		
Annoying*	Male	40	4.27	1.09	.023	.491
	Female	37	4.26	1.05		
Competitive*	Male	40	4.32	.78	.257	.399
	Female	37	4.26	1.11		
Active	Male	40	3.81	1.16	.478	.317
	Female	37	3.68	1.62		
Curious	Male	40	3.84	.92	.171	.432
	Female	37	3.79	1.38		
Cooperate	Male	40	3.89	1.10	.519	.303
	Female	37	3.77	1.03		
Involved	Male	40	3.73	1.20	1.045	.150
	Female	37	3.47	.98		
Successful	Male	40	4.24	.97	1.811	.037*
	Female	37	3.82	.94		
Total	Male	40	3.98	1.02	1.538	.069
	Female	37	3.80	1.12		

*negative item

Male students felt "successful" the most during small-group inquiry activities, which was statistically significant compared with female students ($p < .05$). However, it was confirmed that lower secondary school students, regardless of gender, felt generally negative feelings such as anxiety or competition while conducting small-group inquiry activities ($p > .05$). Therefore, it is necessary to make efforts to reduce anxiety and negative mood that lower secondary school students feel in science inquiry activities.

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Discussion

Most of the external experiences of grade 6 students in the Republic of Korea during inquiry activities were related to class activities, but there were many internal experiences unrelated to inquiry activities. In the stage of inquiry activity, approximately 1% of other actions and thoughts were unrelated to the inquiry activity, including personal actions, small talk, game thoughts, and break time thoughts, which are external actions (Table 4). On the other hand, the frequency of others (D) in internal experience was 23%–27% (Table 5). This means that students experience the inquiry in action but think about thoughts that are unrelated to the inquiry. In other words, about 1/4 of all students are unable to concentrate during small-group inquiry activities and engage in small talk, jokes, or personal actions and thoughts that are unrelated to the inquiry activities. These results indicate that many lower secondary school students feel that the inquiry activities are not enjoyable or interesting. Comparing this finding to the results of Kim and Yang (2005), inquiry activities can act as one of the causes of disliking science.

In terms of external experience, students mainly conducted experiments with peers or conversed with peers about experiments rather than listening to the teacher's directives. nevertheless, approximately 20% of the external experiences experienced by students listened to the teacher's directives as the main action. This means that the main focus is on the inquiry under the directive of the teacher, rather than on the self-directed inquiry by the student. Therefore, a method to guide students to self-directed inquiry activities is required. In addition, verbal interaction (i.e., conversation with peers about experiments) frequently occurred in the variable control stage. Consistent with previous studies (Yu & Choi, 2012), students' spontaneity and high social interaction are required in the variable control and experimental design stages. Accordingly, it could be inferred that this was because one of the reasons for the low verbal interaction of students during inquiry activities was that they did not proceed with the variable control stage (Kim & Kim, 2012; Kwon & Kim, 2016).

In the results of the main actions of external experiences at each stage of inquiry, students in the Republic of Korea have a low level of variable control ability formation; in the case of lower secondary school students, many lack variable control ability (Kim & Kim, 2012). Thus, there is a high possibility of feeling negative emotions. The lack of awareness of variables can act as a cause of experimental performance failure (Germann et al., 1996). Since students can learn the contents related to simple variable control and training is effective (Lawson & Wollman, 2003), it is necessary to provide and implement a program for the variable control stage for lower secondary school students.

On the other hand, it was confirmed that students did not perform activities related to conclusion drawing, such as conducting experiments or conducting observations, in the conclusion drawing stage. This finding is consistent with that of Lim et al. (2011), who found that lower secondary school students have difficulties in interpreting data and drawing conclusions. Data interpretation is a high-level inquiry function and is a scientific literacy required of students in relation to the rapid increase in the amount of information in modern society (Gotwals, 2006). Moreover, data interpretation must be preceded in order to draw conclusions (Lim et al., 2011). Therefore, it is necessary to support activities such as cultivating the ability to identify the relationship between two variables (Kanari & Millar, 2004) or enhancing data interpretation skills through experience in graph interpretation (Choi et al., 2001) for lower secondary school students to perform data interpretation and conclusion drawing.

Students were engaged in activities that did not correspond to the inquiry stage. For example, in the observation stage, there was a student who prepared an experiment, conducted an experiment, and predicted the result of the experiment. There were students who did not design the experiment, but rather prepared and performed the experiment in the variable control stage and made predictions in the conclusion drawing stage. This is because students do not clearly distinguish which activities need to be or do not need to be performed at each stage of inquiry.

Students thought that their activities were helpful to their peers in inquiry activities. This can be inferred from the result that the main activity is the progress of the experiment with the peers or the conversation about the experiment accounted for more than 70% (Table 3). However, more interaction took place in the variable control stage than in the other exploration stages (Table 4). In other words, a variable control step should be included to increase the interaction between students during inquiry activities.

As the result of internal experiences, "teacher's guidance", "interest", and "help" were included regardless of gender in the consciousness and emotions. This is in line with the results of previous studies (Hofstein & Lunetta, 2004; Yang et al., 2006) that inquiry activities help increase interest in and understanding of science.

Students often felt negative emotions, including anxiety, during the inquiry activities regardless of gender. This is consistent with the results of previous studies on scientific anxiety (Jeong & Kim, 2011; Kim et al, 2014). Positive emotions lead to emotional and psychological actions than negative emotions and act as factors that

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increase patience and creativity, giving individuals the strength to adapt well to new and unfamiliar experiences (Ko, 2016). Also, the lower the level of negative emotions such as anxiety or aggression in the small-group inquiry activity, the more positive the perception of the small-group inquiry activity, and the more active the interaction (Yeo & Kim, 2005). Furthermore, it is necessary to make efforts to reduce anxiety and negative mood that lower secondary school students feel in science inquiry activities. In particular, female students were relatively less likely to feel more successful than male students. Therefore, it is necessary to find a way to provide female students with the experience of success in inquiry activities. In addition, it is very important to help lower secondary school students adapt to new and unfamiliar topics through scientific inquiry activities and have positive emotions about the inquiry activities in order to perform well.

Conclusions and Implications

This study analyzed the external and internal experiences experienced by lower secondary school students at each stage during small-group science inquiry activities. First, there was no difference in the external and internal experiences of male and female students in each stage of the inquiry activity. In addition, the main activities performed in the process of inquiry activities were activities related to colleagues and experiments.

Second, there were many cases during inquiry activities in which activities in other stages of inquiry were carried out in addition to the activities that were mainly performed in the corresponding stage. For example, students answered that conducting the experiment was the main action performed in the observation stage, and experiment preparation was performed more than experiment design in the variable control stage. In addition, students responded that they did more experiment preparation, conducting experiments, and observation activities in the conclusion drawing stage (Table 4).

Third, approximately 27% of students said that they had internal experiences unrelated to inquiry during inquiry activities. Also, some students thought that their main actions were not helpful to the inquiry activities. In particular, this was relatively more common in the variable control stage and conclusion drawing stage, which requires a high-level inquiry function, compared with the observation stage, which requires a simple inquiry function. It is considered that there are many cases in which students are unable to participate in inquiry activities that require high-level inquiry skills such as designing and interpreting experiments and interaction with peers. Therefore, it is required to guide all members in the process of inquiry so that they can participate in inquiry activities. Through this, it is hoped that students will become interested in science through inquiry activities.

Fourth, there was little difference between genders in the internal and external experiences experienced in the process of conducting scientific inquiry, but female students were found to have relatively fewer internal experiences that made them feel more successful than male students. This may lead to differences in science-related attitudes between male and female.

Based on the results, it is suggested to include a variable control step in designing the experiment to allow students to actively interact during inquiry activities. However, some differences emerged in attitudes toward science, such as feeling successful about science. This difference in attitudes toward science despite the same experience can adversely affect the success of scientific inquiry. Therefore, it is necessary to provide female students with a successful internal experience to increase their confidence and attitude toward science, while equal inquiry activities that do not discriminate according to gender are carried out. Moreover, as 20% of the students considered listening to the teacher's directive as their main activity, it is expected that the inquiry activity will become a student-centered inquiry activity. Since this study analyzed experiences in open-ended inquiry, it is expected that the analysis will be conducted in various forms of inquiry, such as guided inquiry.

Declaration of Interest

The authors declare no competing interest.

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COGNITION AND ATTITUDE TOWARD SUSTAINABLE DEVELOPMENT BEHAVIOR: COLLEGE STUDENTS' INFORMAL ONLINE LEARNING AS A MODERATION EFFECT

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Abstract. *The social responsibility of college students in the later stages of adolescence for sustainable development is emphasized, and the role of universities has become a crucial task. This study aimed to explore the level of college students' cognition, attitude, and behavior towards sustainable development and the association among them through the moderation effect of informal online learning. The difference verification and structural equation modeling were applied to 559 students who majored in science, and statistical validity was confirmed. Regarding the sustainable development level of college students, there was a significant difference in cognition, attitude, and behavior towards sustainable development between males and females, formal education, and informal online learning. Further, college students' attitudes towards sustainable development played a significant mediating role between cognition and behavior. The study also found a significant moderation effect of informal online learning on students' cognition and attitude toward sustainable development behavior. Accordingly, this study suggests that universities should systematically design educational programs to promote college students' behavioral change toward sustainable development through personal life-oriented learning courses.*

Keywords: *sustainable development behavior, sustainable development cognition, sustainable development attitude, college student, informal online learning*

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Introduction

As society continues to prioritize rapid economic development and growth, excessive development, and consumption have led to the depletion and degradation of resources, environmental destruction and pollution, and global warming. These ecological problems have become important global issues (Andersen et al., 2018; Choi et al., 2010; UNESCO, 2005). To address these issues, it is necessary to strengthen education for awareness and understanding of sustainable development. Especially for college students, as the backbone of future society, their cognition and behavior have a crucial impact on the sustainable development of future society (Ávila et al., 2019; Wals & Jickling, 2002; Walshe, 2017).

Many universities offer courses on sustainable development to educate students on how to contribute to society and the environment (Tilbury, 2004; Veidemane, 2022). The significance of conducting sustainable development education in universities lies in the fact that the college's responsibility extends beyond imparting knowledge, as it also involves cultivating the personality and values of its students.

In addition, as part of society, college students have a direct impact on the environment and society through their behavior and habits. Providing sustainable development education and training for college students can cultivate their environmental awareness and sustainable development concepts, guiding them to adopt sustainable lifestyles and make contributions to the future sustainable development of society (Min, 2019; Shephard, 2008).

Furthermore, the current use of digital media is recognized as an important communication tool, and it is attracting attention as an optimal tool for realizing social learning as it enables knowledge and information sharing, dissemination, communication, and collaboration (Lim et al., 2012). College students obtain information related to sustainable development through mass media and provide opportunities for activities related to sustainable development through methods such as online forums (Hori & Fujii, 2021).

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With this social trend, personal learning using information and communication technology (ICT) is increasing and evolving as a tool for informal learning (Kim & Yi, 2011).

Nevertheless, sustainable development is still mostly at a theoretical level, and students' perceptions and actions toward the environment need to match the current environmental problems (Shephard, 2008; Vandemoortele, 2018). Most previous studies have tended to separate the cognition, attitude, and behavior of sustainable development (Michalos et al., 2011; Min, 2019; Torbjörnssona, 2011), and empirical studies on the association between these factors have been limited. In this context, this study explores the association between personal characteristics and factors influencing sustainable development to enhance the sustainable development behavior of college students.

Literature Review

College Students' Sustainable Development

Ever since the World Commission on Environment and Development (WCED) defined sustainable development in 1987 as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs', the complexity of sustainable development due to its characteristics, there have been various interpretations and criticisms in its definition. Among them, this study conceptualizes sustainable development as the comprehensive development strategy for the 21st century that emphasizes the integration and balance among the environment, economy, and society, based on the global agenda of the UN (2015) and the Triple Bottom Line theory (TBL theory) of Elkington and Rowlands (1997).

In particular, the Chinese government and the Ministry of Education recognize the importance of sustainable development as a national and global agenda and are implementing a series of policies and measures to promote the sustainable development of university students. In this regard, in 2019, the China Center for Environmental Protection and Publicity and Education issued the '*Guidance Opinion on Strengthening the Construction of Ecological Civilization in Higher Education*' to strengthen ecological civilization education in universities and cultivate students' awareness of environmental protection. It has been announced that university education will promote the construction of an ecological civilization.

In addition, in China, influenced by the Rio Conference in 1992, education for sustainable development tends to be discussed centering on environmental education (Qu, 1993), and education for sustainable development for college students also emphasizes environmental protection and resource conservation (Pan, 2015). Recently, in order to promote a sustainable development policy called *'Green Walk'*, sustainable development using eco-friendly transportation is supported (Chen, 2014; Wang et al., 2018). For example, there are attempts by college students to reduce resource waste and carbon emissions by using new transportation methods such as shared bicycles and carpools (Shen & Liu, 2017; Wang et al., 2018).

Nevertheless, there are still some limitations in the cultivation of sustainable development among Chinese college students. First, many college students have received less education on sustainable development due to the lack of curriculum and educational resources (Huang, 2014; Yang et al., 2017). Second, as some college students lack in-depth thinking about sustainable development, they tend to underestimate the value of the environment and resources and lack action and initiative to promote sustainable development (Hu, 2013; Zhang, 2020). In addition, studies that can further strengthen the combination of theory and practice in the field of sustainable development to improve the practical ability of college students for sustainable development are needed (Yang et al., 2017; Yi & Lu, 2022; Yu & Yang, 2019).

Accordingly, it is important for all stakeholders, including government, civil society organizations, corporations, and universities, to collaboratively design and implement practical plans that incorporate sustainable development principles and visions. Additionally, educating individuals about sustainable development should be a priority (Hesselink, 2000; UNESCO, 2005).

Factors Influencing Sustainable Development

Sustainable development has become a critical issue in higher education institutions worldwide, as they are not only responsible for equipping students with knowledge and skills to address global sustainability challenges but also must lead by example and implement sustainable practices themselves. However, implementing sustainable practices in higher education institutions has its challenges (Tilbury, 2004; Veidemane, 2022). According

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to Ávila et al. (2019), higher education institutions around the globe face a multitude of challenges that hinder students' promotion of sustainable development, and this is equally true for Asia. Among those challenges, this study explored the structural association between sustainable development cognition, attitude, and behavior among college students.

Firstly, Michalos et al. (2011) argued that the association between cognition and attitude toward sustainable development is stronger than other associations and that the association between cognition and behavior is also significant. It has been shown that there is a statistical correlation between cognition and behavior (Yoo & Lee, 2014), and that there is also a significant correlation between attitude and behavior (Min, 2019; Walshe, 2017). In addition, studies conducted by Yoo and Lee (2014) and Yoo and Oh (2016) provided evidence supporting the view that cognition has a substantive impact on behavior. The research conducted by Yoo and Oh (2016) also suggested that attitudes play an important role in shaping individual behavior. In other words, even in the absence of external pressure or incentives, an individual's views on a particular issue or behavior strongly influence their actions.

When considering previous studies, one thing to consider in studies of college students' cognition and related behaviors on sustainable development is whether there is a difference in gender, formal education (sustainable development learning experience in college) and informal online learning (using ICT for sustainable development).

Recent studies have shown that females are more interested in the environment and more sensitive to environmental issues than males, resulting in a significant difference in females' cognition and behaviors for sustainable development compared to males (Min, 2019). Furthermore, previous studies have demonstrated that individual value systems can also play a significant role in shaping attitudes towards sustainable development. For instance, individuals who prioritize human-centered values, such as care for others and social justice, tend to have more positive attitudes towards sustainable development than those who prioritize self-enhancement values, such as achievement and power (Torbjörnssona, 2011).

In addition, classes related to sustainable development at school can help college students understand the concepts and principles of sustainable development, and through these classes, college students can understand the meaning and background of sustainable development, thereby contributing to raising awareness of sustainable development (Mahtab & Asghar, 2021). Similarly, Janmaimool and Khajohnmanee (2019) found that students with a learning experience in sustainable development have more positive attitudes than students without a learning experience and related to sustainable development in school can promote positive attitudes, and the attitude influences environmental behavior.

Hori and Fujii (2021) suggested that due to the rapid development of ICT, an increasing number of students are learning about sustainable development through the Internet or mobile phones and that college students actively collect information related to sustainable development. It can positively influence the values of people to support sustainable development and take more action on sustainable development (Gu, 2022).

Understanding these associations and differences, this study can provide insights into how college can better educate and engage students on sustainable development, and how individuals can be encouraged to adopt more sustainable behaviors in their daily lives. Therefore, the following three research questions were posed:

1. Are there differences in cognition, attitude, and behavior of sustainable development among college students?
2. Is there a mediating effect of attitude between cognition and behavior of sustainable development?
3. Do influences of sustainable development attitudes on behavior differ according to gender and learning experiences?

To address these questions, the study formulated an analytical model, using "the cognition of sustainable development" as the independent variable, "attitude" as the mediating variable, and "behavior" as the dependent variable. The association between the variables is illustrated in Figure 1. Building on the prior studies, this study constructed both partial and full mediating analytical models, considering the findings of some studies that indicate no direct effect of the cognition of sustainable development on behavior. Min (2019) suggested that an association that could affect behavior is inconclusive in a state where the knowledge level of sustainable development is low. This may be because sustainable development cognition is transferred to action only when it is internalized into an attitude. Therefore, this study also included a *full mediating model* (Figure 2) that suggests that cognition does not have a direct impact on behavior. Finally, in order to further verify the model validity, this study considered the moderation effect on the structural model of gender, formal education experiences, and informal online learning

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related to sustainable development (Figure 3). By verifying the statistical significance of the moderation effect, the study intended to enhance the explanatory and predictive power of the research model.

Figure 1
Partial Mediating Model

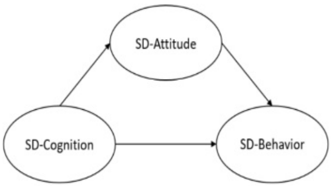


Figure 2
Full Mediating Model

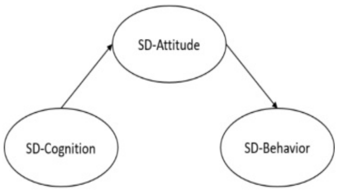
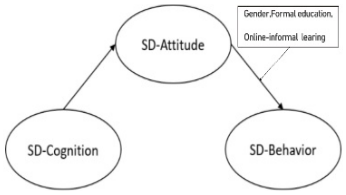


Figure 3
Meditation Model by Multi-group



Research Methodology

Research Design

This study is quantitative research aimed at examining the levels of college students' cognition, attitude, and behavior towards sustainable development and the associations among these variables. A survey questionnaire was administered to undergraduate students from a comprehensive university in China, and a structural equation modeling approach was used to analyze the data.

The survey was conducted for one month from May to June 2022. The questionnaire was distributed during the night self-study time of the students, and before completing the questionnaire, the students read and signed the informed consent form that explained the purpose of the study and the confidentiality of the survey responses.

Participants

Study participants are recruited from the only four-year university in C City, a city abundant in natural resources. The university has established departments related to sustainable development and carries out related activities to promote cognition, attitude, and behavior of sustainable development among students majoring in science-related fields. In this study, a sample was chosen from this university to obtain representative data on sustainable development. Students enrolled in grades 1 to 4 were included in the sample to reflect the various levels of sustainable development. There were slightly more male students (308, 55.1%) than female students (251, 44.9%). By grade, the sample consists of 169 first-year students (30.2%), 134 second-year students (24.0%), 125 3rd-year students, and 131 4th-year students (24.4%). Finally, the study analyzed the distribution of students with prior formal educational experience and informal online learning. Of the students surveyed, 216 students (38.6%) had prior formal educational experience, while 343 (61.4%) students did not have such experience. Regarding informal online learning, 310 students (55.5%) indicated a higher level of informal online learning than the overall average, while the rest, 249 students (44.5%) had a lower-than-average level.

This study collected 580 questionnaires, of which 559 copies were put into the analysis, excluding 21 questionnaires that were answered insincerely. Although the sample size is small, this study adopted a rigorous sample selection process and ensured the representativeness and diversity of the sample.

Measurements

The study adopts a measure of cognition, attitude, and behavior of sustainable development targeting young people, developed by Michaelos et al. (2011). This measurement tool is considered reliable and consistent: the overall reliability of the cognition tool is Cronbach's α = θ.790, the attitude tool is Cronbach's α = 0.770, and the behavior tool is Cronbach's α = 0.630. This measurement tool consists of 47 items, but this study uses items found to be reliable, removing the items with values less than 0.6 on the reliability index. The measurement tool used in this study consists of a total of 24 items, comprised of 9 items for cognition, 5 items for attitude, and 10 items for

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behavior. To ensure the content validity of the measurements, three education experts reviewed the contents of each item and confirmed the suitability of the final 24 items. Each item is reported on a Likert 5-point scale (1 = not at all; 5 = very much), where higher scores signify higher levels of awareness, attitude, and practice of sustainable development.

To verify the validity of the measurement tools, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were conducted (shown in Table 1). In the process of exploratory factor analysis, principal component analysis was performed to extract three factors. Twenty-four items with factor loadings exceeding 0.5 and no cross-loading were maintained. The goodness of fit of the KMO sample is judged to be acceptable when it is 0.6 to 0.7 or higher, and the factor analysis result is 0.966, and in Bartlett's sphericity test, the significance probability is 0.000 and the significance level $p < 0.001$, and the model is confirmed to be suitable. Next, CFA was performed to evaluate the structure of factors derived by EFA. The model fit index was $\chi^2/df = 2.284$ (< 3), TLI = 0.960 (> 0.9), CFI = 0.964 (> 0.9), and RSMEA = 0.048 (< 0.05), confirming that the model was appropriate. In addition, in CFA, the factor loading is between 0.550 and 0.780, the average variance extraction (AVE) value is between 0.467 and 0.565, and the combined reliability (CR) value is between 0.867 and 0.905. The measurement tool of this study was found to be appropriate.

The Cronbach's alpha values of the last question on the survey for the cognition, attitude, and behavior measurements were 0.928, 0.898, and 0.917 respectively, which met the acceptance standard of over .6 for reliability. This study performed confirmatory factor analysis to evaluate the fit of the measurement model.

Table 1
Validities of the Sustainable Development Items

Items	Mean	EFA	CFA
SD-Cognition (Cronbach's α 0.928, CR 0.905, AVE 0.514)			
C1. Economic development, social development and environmental protection are all needed for sustainable development	3.75	0.651	0.698
C3. Sustainable development is about both future needs and what we need today	4.00	0.708	0.741
C5. China's overall use of energy remains to be improved	3.93	0.778	0.849
C9. Sustainable development tries to balance human and economic success with cultural traditions and respect for the earth's natural resources	4.48	0.764	0.809
C10. We can slow the rate of climate change	3.53	0.692	0.751
C12. Conservation of fresh water is not important in China because we have plenty	3.69	0.717	0.792
C13. Maintaining biodiversity is essential to the health of ecosystems	3.64	0.738	0.802
C15. Non-renewable resources should not be used faster than the rate at which we find substitutes that are renewable	3.71	0.666	0.755
C16. It is useful to estimate the monetary value of the services that the ecosystem provides to us	3.69	0.731	0.772
SD-Attitude (Cronbach's α 0.898, CR 0.867, AVE 0.565)			
A3. Companies should try to avoid making design disposable products	3.57	0.764	0.831
A5. Laws and rules to protect the environment need to be more strict than they are now	3.29	0.751	0.793
A8. Companies that are environmentally responsible are more likely to make a profit over the long run	3.57	0.755	0.832
A10. Governments should encourage greater use of fuel-efficient vehicles	3.62	0.780	0.704

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Items	Mean	EFA	CFA
A13. Taxes on polluters should be increased to pay for damage to communities and the environment	2.67	0.707	0.837
SD- Behavior (Cronbach's α 0.917, CR 0.897, AVE 0.467)			
B1. I walk or bike to places instead of going by car	3.89	0.739	0.779
B2. I use reusable containers in order to reduce waste	2.85	0.669	0.69
B3. At home, I try to recycle as much as I can	3.23	0.622	0.707
B5. I have taken a course in which we talked about sustainable development	3.36	0.703	0.799
B7. I pick up litter when I see it in a park or a natural area	2.53	0.664	0.712
B8. I often look for signs of damage to our environment	2.53	0.750	0.830
B10. I sort the trash before I throw it away	3.32	0.665	0.687
B12. I try to avoid purchasing goods from companies with a poor track record on caring about their workers or the environment	4.09	0.705	0.784
B13. I have changed my personal lifestyle to reduce waste	3.03	0.550	0.675
B14. I have studied some issues related to climate change	2.90	0.744	0.759

Data Analysis

To ensure the quality and reliability of the collected data, several statistical analyses were conducted. Firstly, descriptive statistical analysis was conducted to obtain the basic information of the data, such as the mean, standard deviation, and range of each variable. In addition, Cronbach's alpha coefficient was calculated to measure the internal consistency of the items and ensure the reliability of the measurement tool. Moreover, the questionnaire was translated back into Chinese, and CFA was conducted for the validity of the measurement tool. In this study, the hypothesized latent constructs were cognition, attitude and behavior of sustainable development, and the observed variables were the items in the questionnaire. Furthermore, the study explored the differences in sustainable development according to personal background variables such as gender, formal education, and informal online learning by conducting independent t-tests. By examining the differences in sustainable development between different groups, the study can gain insights into how personal background variables affect sustainable development behaviors. To explore the association between cognition, attitude and behavior of sustainable development, a structural equation model (SEM) was constructed, and the mediating effect of attitude was verified. Finally, a multi-group analysis was conducted to verify the moderation effects of gender, university class experience related to sustainable development, and informal online learning. All of the aforementioned analyses were conducted using SPSS 26.0 and AMOS 26.0 programs, which are commonly used statistical analysis software.

Research Results

Differences in Sustainable Development Behavior

In order to understand the level of cognition, attitude, and behavior of university students on sustainable development, the study examined the differences by gender, class experience, and ICT activity (shown in Table 2). Overall, the behavior of sustainable development (M = 3.17) was the lowest.

The disaggregated analyses show that there are statistically significant differences in cognition (t = -3.14),

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attitude (t = -2.72), and behavior (t = -2.14) of sustainable development by gender. The findings indicate a significant difference by gender, with higher levels of cognition, attitude, and behavior of sustainable development of female students than those of male students. With regard to SD-related formal education experience, there were statistically significant differences in cognition (t = 8.40), attitude (t = 4.88), and behavior (t = 7.62) about sustainable development. It was confirmed that students with experience taking SD-related classes have higher levels of cognition, attitude, and behavior than students without class experience. With regard to informal online learning, the study found a statistically significant difference in the cognition of sustainable development (t = -9.44), attitude (t = -7.79), and behavior (t = -9.02). The findings confirm that the students with informal online learning have higher levels of sustainable development.

Table 2
Comparing the Differences based on Personal Characteristics

Distinction		SD-Cognition		SD-Attitude		SD-Behavior	
		M(SD)	*t*	*M(SD)*	*t*	*M(SD)*	*t*
Total		3.82(0.69)	-	3.34(0.96)	-	3.17(0.74)	-
Gender	Male	3.74(0.68)	-3.14**	3.24(0.97)	-2.72**	3.11(0.74)	-2.14*
	Female	3.93(0.69)		3.46(0.93)		3.25(0.74)	
Formal education experience	Yes	4.11(0.53)	8.40***	3.59(0.89)	4.88***	3.46(0.70)	7.62***
	No	3.64(0.72)		3.19(0.96)		2.99(0.71)	
Informal online learning	High level	4.06(0.53)	9.44***	3.61(0.83)	7.79***	3.41(0.70)	9.02***
	Low level	3.54(0.76)		3.01(0.99)		2.88(0.69)	

Note. *p < .05, **p < .01, ***p <.001

Verification of the Mediating Effect of Sustainable Development Attitude

In order to further analyze the association among sustainable development cognition, attitude and behavior, this study set the attitude towards sustainable development as the mediating variable and compared the fit of the partial mediating model and the full mediating model as shown in Table 3. Both models met the criteria of being less than .08 for root mean square error of approximation (RMSEA) and higher than .90 for Tucker Lewis index (TLI) and comparative fit index (CFI). The difference in chi-square values between the partial mediating model and the full mediating model was 125.767, which was significant as it was larger than the threshold of 3.84 for the difference of 1 degree of freedom. However, the chi-square test can only verify whether the model is significant but cannot determine which model is better. Therefore, other indicators, such as the Akaike information criterion (AIC) were needed to evaluate the models. The smaller the AIC value, the more simplified and the better fit the model (Akaike, 1974). The full mediating model has the smaller AIC value in this study, so it was determined to be the more suitable model.

Table 3
The Fitness of the Mediating Research Model

Model	df	χ^2/df	TLI	CFI	RSMEA	AIC
Partial Mediating	250	2.778***	0.945	0.950	0.056	842.381
Full Mediating	249	2.284***	0.960	0.964	0.048	718.614

Note. ***p < 0.001

The result of the path coefficient analysis in the final model, which is the full mediation model, as seen in Figure 4, showed that all path coefficients were significant at p < 0.001. It indicates that cognition of sustainable

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development has a positive effect on attitudes (β = 0.74, $p < 0.001$) and attitudes have a positive effect on behaviors (β = 0.76, $p < 0.001$). This suggests that as students' cognition of sustainable development increases, their attitudes towards sustainable development also strengthen. In turn, as their attitudes towards sustainable development strengthen, their sustainable behaviors also increase. These findings provide valuable insights for educators and policymakers to develop effective strategies to promote sustainable development among college students.

This study used bootstrapping to verify the mediation effect, and the sampling time was 2000. As shown in Table 4, the mediating variable, attitude, had a significant effect between cognition and behavior, and the indirect effect value was 0.556 (Bias-corrected 95% *CI* = 0.490 ~ 0.616). The confidence interval did not include 0 and the p-value was less than .001, which confirmed that attitude had a mediating effect. Therefore, the results highlight the importance of promoting positive attitudes towards sustainability to encourage sustainable behavior among college students.

Figure 4
Path Diagram and Standardized Estimate of Research Model

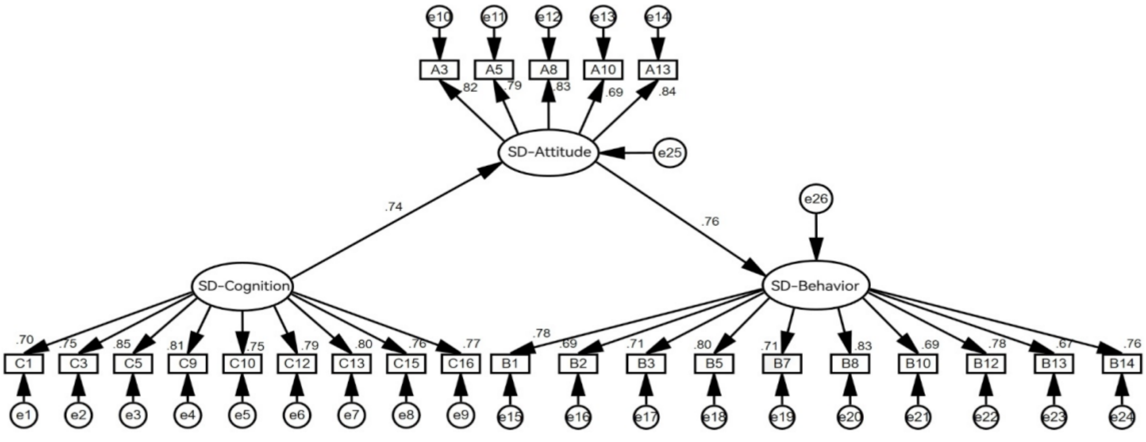

Table 4
Significance Verification of Mediating Effect

Path	Estimate	S.E.	Bootstrap 2000 times 95% bias-corrected CI
Cognition → Attitude → Behavior	0.556***	0.044	0.490 ~ 0.616

Note. ***$p < .001$

Verification of the Multi-group Comparison

Finally, a multi-group analysis was conducted to verify the moderation effect of gender, formal education (sustainable development learning experience in college), and informal online learning (using ICT for sustainable development). A measurement equality test was conducted to check whether the variables were equally recognized according to gender, formal education, and informal online learning. It was confirmed that the goodness-of-fit indices of all models were acceptable, as shown in Table 5.

The model fit according to gender confirmed that χ^2/df = 2.640 (< 3), CFI = 0.901 (> 0.9), and RMSEA = 0.054 (< 0.08), indicating an acceptable fit. The model fit according to educational experience showed that χ^2/df = 2.648 (< 3), CFI = 0.890, and RMSEA = 0.054 (< 0.08). The model fit according to informal online learning revealed that χ^2/df = 2.875 (< 3), CFI = .871, and RMSEA = 0.058 (< 0.08). Although the CFI value is slightly lower than 0.9, considering the other goodness-of-fit indices, the model was deemed acceptable.

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Table 5
Nested Multi-group Model Fits

Structural residuals	χ^2/df	CFI	RMSEA
Gender	2.640***	0.901	0.054
Formal education experience	2.648***	0.890	0.054
Informal online learning	2.875***	0.871	0.058

Note. df = 573, ***$p < .001$

The findings showed that the sustainable development cognition of the two groups by gender had a positive (+) significant effect on attitude ($p < .001$), and attitude had a positive (+) significant effect on behavior. ($p < .001$). Since the difference between 'cognition → attitude path' between male and female groups is .794, and the difference between 'attitude → behavior path' 1.616 is smaller than |1.96|, the difference in path is not statistically significant. As a result, the findings indicate no difference in the effect of attitudes toward sustainable development on practice according to gender. That is, the moderation effect of gender was not significant.

The findings showed that the cognition of sustainable development of the two groups had a positive (+) significant effect on their attitude ($p < .001$), and attitude had a positive (+) effect on behavior. It was found to have a statistically significant effect ($p < .001$). Since the difference in 'cognition → attitude path' between groups with or without class experience is 0.659, and the difference in 'attitude → behavior path' -1.477 is smaller than |1.96|, the difference in path is not statistically significant. Accordingly, the moderation effect of class experience at university was not significant.

The findings also reveal that the cognition of sustainable development of the two groups according to informal online learning has a positive (+) significant effect on attitude ($p < 0.001$), and attitude had a positive (+) significant effect on behavior ($p < .001$). The difference in the 'cognition → attitude path' between the below and above-average groups in informal online learning was 1.963, and the difference in the 'attitude → behavior path', 2.365, was greater than |1.96|, so the difference in the path was statistically significant. Accordingly, it was found that there was a difference in the effect of attitudes toward sustainable development on behavior according to informal online learning. In other words, the moderation effect of informal online learning was significant in the structural relationship of sustainable development (shown in Table 6).

Table 6
Significance Verification of Multi-group Path Analysis

Path toward gender	Male		Female		Between groups
	β	*SE*	β	*SE*	
Cognition → Attitude	0.712***	0.084	0.737***	0.100	0.794
Attitude → Behavior	0.699***	0.044	0.819***	0.051	1.616
Path toward formal education	**Yes**		**No**		**Between groups**
	β	*SE*	β	*SE*	
Cognition → Attitude	0.655***	0.113	0.739***	0.086	0.659
Attitude → Behavior	0.756***	0.059	0.726***	0.040	-1.477
Path toward informal online learning	**High level**		**Low level**		**Between groups**
	β	*SE*	β	*SE*	
Cognition → Attitude	0.709***	0.116	0.673***	0.094	1.963
Attitude → Behavior	0.759***	0.052	0.675***	0.046	2.365

Note. ***$p < .001$

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Discussion

Sustainable Development Level and Differences

As the world grapples with climate change, resource depletion, and social inequality, sustainable development has become imperative for college students expected to uphold social responsibility. However, despite the growing cognition and acceptance of sustainable development among students, the current study showed that their actual behaviors need to catch up with their level of cognition and attitude toward it. This is in line with the results reported by Andersen et al. (2018), Ávila et al. (2019), and Hesselink (2000), which also emphasized that students' behavior of sustainable development is not sufficient in their daily life. Moreover, Ávila et al. (2019) confirmed the lack of applicability and continuity of actions as a major barrier to practicing sustainable development. If the university's policy efforts to foster sustainable development remain one-off, it becomes difficult to expect sustainable development's ultimate change and growth.

In sequence, this study compared the level of sustainable development by gender and educational experiences and found their significant differences. This aligns with the findings conducted by Atik et al. (2022), Torbjörnssona (2011), Yoo and Oh (2016) and Zhou (2017). Yoo and Oh (2016) insisted that the difference between males and females may be somewhat limited, but gender with high sensitivity to sustainable development can be linked to behavior. In particular, this study found that female students had significantly higher levels of sustainable development cognition and attitude, which suggests that females are more aware and concerned about environmental issues than males. In this regard, Atik et al. (2022) confirmed that females preferred sustainable lifestyles, such as purchasing eco-friendly products, and in this study, females' sustainable development cognition was the highest at 3.93(shown in Table 2) compared to other areas of sustainable development.

The current research found differences in sustainable development according to school or personal learning experiences, corroborating the findings of prior studies (Gu, 2022; Hori & Fujii, 2021; Lee, 2019; Mahtab & Asghar, 2022). Schools can help college students understand the concepts and principles of sustainable development, and they can raise their cognition of sustainable development by understanding the meaning and background of sustainable development through classes (Mahtab & Asghar, 2022). Gu (2022) also argued that personal online learning opportunities linked to school classes contribute to further strengthening learning outcomes. In the process of actively collecting related digital information, sustainable development behavior can be further increased by positively affecting the values of college students.

The Association of Cognition and Attitude toward Sustainable Development Behavior

The current study revealed that both sustainable development cognition and attitude significantly impact behavior. Specifically, cognition acted as an influencing factor, and attitude acted as a mediating factor. These findings are consistent with previous studies conducted by Yoo and Lee (2014), Michalos et al. (2011), and Min (2019), which also found a significant correlation between cognition-attitude behavior and attitude-behavior of sustainable development. Yoo and Lee (2014) revealed that attitudinal factors mediate the association between environmental cognition and behavior, suggesting that attitude plays a crucial role in translating environmental knowledge into sustainable behavior.

This study adds to the body of literature by providing empirical evidence for the structural causal association between cognition, attitude, and behavior toward sustainable development. In this regard, as Blake (2001), and Ma and Zhao (2008), sustainable development behavior affects complex factors by operating comprehensively. This study particularly revealed the full mediating effect of sustainable development attitudes. Moreover, it expands on previous research by providing empirical evidence of the mediating effect of attitude on the association between cognition and behavior. Applying these findings to the cognitive behavior model (Ellis, 1978; Frijda, 1993), when students encounter sustainable development knowledge as an event, they perceive it through their own system or evaluate the knowledge in light of their attitudes. As a result, emotional or behavioral consequences are expressed. At this time, college students' original attitude and values may cause an additional outcome that further strengthens the related sustainable development attitude. This finding has significant implications for sustainable development interventions, as it suggests that phased interventions targeting cognition and attitude may be more effective in promoting sustainable behavior.

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The Moderation Effect of Informal Online Learning

In this study, only the moderation effect of informal online learning was significant among the assumed personal characteristics within the relationship between sustainable development cognition-attitude-behavior. On the other hand, the study found no significant difference between groups according to the educational experience at the college. These findings are in line with prior study findings by Huang (2014), Yang et al. (2017), and Yi and Lu (2022). Huang (2014) and Yang et al. (2017) criticized the limitations of the current status of superficial sustainable development education in Chinese colleges, and this study is related to the assumption of sustainable development behavior as a dependent variable. In other words, the current college education is insufficient to induce changes in students' sustainable development behavior. In addition, as Yi and Lu (2022) argued, related implementation strategies and preparation of alternatives are required due to the lack of research dealing with college students' sustainable development behavior.

In the difference test, female students' attitudes and behavior toward sustainable development were higher than male counterparts. However, the causal relationship between these three factors showed that the difference according to gender was insignificant. These comparative research results are related to the studies of Huang (2014) and Min (2019). Rather than a tendency for female students' high-level sustainable development attitudes to be consistently linked to behavior, personal characteristics by gender, such as 'males are more actively interested in eco-technologies and sustainable energy (Huang, 2014)'. It can be interpreted that tastes are expressed more preferentially. In particular, since this study focused on students in major science, as Yu and Yang (2019) argued, the characteristics of each major, in addition to gender, may have an impact.

In sum, these findings suggest the prospect of using informal online learning to foster sustainable development behavior and provide support for using informal online learning. Hori and Fujii (2021) and Kim and Yi (2012) confirmed the increase in personal learning using ICT among young people in the 21st century and identified information sharing and communication in the online space as the best tools for learning. Considering the preferences and characteristics of college students in the MZ generation, we should recognize the significance of utilizing the digital space and ICT in education. Therefore, it is necessary to reflect on whether the national and policy attempts to foster sustainable development are being promoted in practice and whether the characteristics of university students as learners are actively reflected (Zhang, 2020).

Conclusions and Implications

This study aimed to examine the level of cognition, attitude, and behavior towards sustainable development and to verify the association among them through the moderation effect of informal online learning to enhance sustainable development behavior. In addition, various statistical processes were calculated to predict the final influencing factors for the accuracy of the research results. Therefore, the significant mediating role of sustainable development attitude and the moderation effect of informal online learning was confirmed. The study is expected to contribute to the sustainable development agenda by highlighting the need for targeted educational strategies to promote sustainable practices among young people. The above conclusions provide important messages for universities seeking to promote sustainable development education among college students.

The study emphasizes the importance of prioritizing attitude improvement as a prerequisite for effective sustainable development practice. It is not enough to provide information and knowledge about the seriousness of environmental issues. Sustainable development education must also aim to increase students' sense of need and empathetic attitude towards sustainable development. Moreover, the study highlights the need for college students to take an active and positive approach to sustainable development education. Equipping students with the knowledge, skills, and attitudes needed to address the complex challenges facing the world today is crucial for promoting a sustainable future. To that end, universities should play a critical role in promoting sustainable development education among college students and prioritize this important agenda in their curricula and pedagogical practices.

Universities also should develop and support a sustainable development education program that considers students' evolving needs and growth. In particular, universities should explore approaches that promote

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behavioral change through personal life-oriented learning courses. This study proposes an experienced approach to sustainable development education, which interconnects non-formal education and informal learning in addition to university education. This holistic approach recognizes the interconnectedness of various personal experiences and suggests that sustainable development education should address these challenges in a comprehensive and integrated way.

Limitations

Nevertheless, this study has several limitations. First, since only college student participants were surveyed, the results may not be directly used by other students or groups with different cultural backgrounds. Second, the effects of cognition and attitude on sustainable development behavior have been considered, but the impacts of other potential variables may still exist. Therefore, to more comprehensively and practically understand sustainable development behavior in future studies, it may be considered to introduce factors such as family and social factors.

Declaration of Interest

The authors declare no competing interest.

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INFLUENCE OF STEM VALUE PERCEPTION ON STEM CAREER PREFERENCES AMONG AGRICULTURAL AND FORESTRY UNDERGRADUATES

Jianjun Sheng, Peiyao Tian, Daner Sun, Yanhua Fan

Abstract: *Currently, nations grapple with a noticeable shortage of STEM talent, particularly within fields like agroforestry. The study applied the structural equation modelling and the mediation effect model to analyze the mechanisms through which STEM value perception influences STEM career preferences, as well as the roles played by STEM self-efficacy and STEM learning interest among 1,604 undergraduates majoring in agroforestry. The results revealed that students' STEM value perception was found to directly and positively correlate with their STEM career preferences. STEM value perception also has an indirect impact on STEM career preferences by influencing STEM learning interest and STEM self-efficacy. Furthermore, STEM value perception plays a sequential mediation role in promoting STEM learning interest, STEM self-efficacy and STEM career preferences. Based on these findings, it is recommended that institutions bolster STEM career education for students majoring in agroforestry from the outset of their enrollment, enhancing students' professional awareness and identity, by addressing gaps in students' value perceptions of STEM education. Furthermore, efforts to improve students' interest in relevant courses and their confidence in learning these subjects can be beneficial. Ultimately, such initiatives can contribute to a more balanced development of students' STEM career preference.*

Keywords: *STEM career preference, STEM learning interest, STEM self-efficacy, STEM value perceiving, Agroforestry undergraduates*

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Introduction

In order to adapt to the changes in the development of the world's economy, society, science and technology and the profound changes in the demand for talent training, countries around the world have strategically formulated policies to promote the training of STEM talents in order to develop the national economy and increase the pool of scientific and technological innovation talents (NRC, 2011; OECD, 2012). However, despite the fact that governments have introduced policies and implemented reforms to improve the quality and quantity of STEM-related talent training at universities, few people are engaged in STEM-related careers after university graduation, and there is still a serious shortage of STEM talent (Gago et al., 2005; OECD, 2018; Stipanovic & Woo, 2017). Consequently, numerous researchers have embarked on exploring the STEM career aspirations of students across all age groups, aiming to gain insights into their preferences within the realm of STEM careers (Carpi et al., 2017; Chachashvili-Bolotin et al., 2016; Lent et al., 2010; Zhan, et a., 2023).

According to Social Cognitive Career Theory (SCCT), an individual's career interest is determined by the core variables of self-efficacy, learning interest, outcome expectations, and learning experience, along the lines of Individual-Behavior-Environment (Lent et al., 2010). Currently, many researchers have explored the status of students' STEM career preferences and the factors that influence students' expectations of pursuing STEM-related careers, such as self-efficacy (Blotnicky et al., 2018), learning interest (Luo et al., 2021), impressions of STEM (Chen et al., 2022), family (Balt et al., 2023), formal or informal learning environments (Cheng et al., 2021; Drymiotou et al., 2021), and so on. While undeniably valuable, a majority of these studies have primarily concentrated on the elementary and secondary education tiers, leaving a noticeable gap in terms of studies conducted at the university level. The significance of this omission becomes particularly pronounced

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when considering that university-level students, typically aged 18 to 23, have already made their major selections. This phase of education is especially pivotal for students within science and engineering fields, as it represents a crucial juncture for assimilating specialized knowledge, refining professionalism, cultivating a sense of professional identity, and nurturing a heightened professional interest (Liu et al., 2022). The STEM career inclinations exhibited by this cohort of students hold a stronger predictive power for their subsequent career trajectories within the field, surpassing the predictive significance observed in students of different age brackets (Liu et al., 2022). Consequently, delving into the STEM career propensities of students enrolled in science and technology programs at colleges and universities holds immense value.

Amidst the swift progression of the latest global scientific and technological revolution, coupled with industrial transformations, the significance of agricultural and forestry disciplines has become even more pronounced. Pioneering technologies encompassing biotechnology, engineering advancements, information technology, and other forefront innovations are consistently permeating the realm of agriculture, fostering an innovative resurgence in agricultural science and technology. This phenomenon presents a series of intricate challenges and requisites for structuring disciplines and specializations, along with nurturing talent, within educational institutions focusing on agriculture (Ameyaw et al., 2017; Sharik et al., 2015). However, data showed that among all STEM majors, the proportion of students majoring in agriculture and forestry who are engaged in majors-related occupations after graduation is the smallest (Kim et al., 2022, World Bank, 2019). Parents and students generally perceive agriculture and forestry majors to be difficult to employ and of little value (Cosby et al., 2022). Therefore, studying the influence of this group's STEM value perception on their STEM career tendency can help relevant professional teachers, schools and the state to analyze the academic situation, improve career education in agricultural and forestry colleges and universities, and cultivate urgently needed and scarce reserve agricultural and forestry science and technology talents.

Based on the above background, this study explored the influence of STEM value perceptions of Chinese agricultural and forestry university students on their future STEM career preferences by means of a questionnaire survey, and explored the mediating roles of STEM learning interests and STEM self-efficacy, with a view to providing references to improve the future STEM career preferences of this group of students.

Literature Review

STEM Career Preference

Career preference encompasses an individual's future career intentions, along with their ambitions and anticipations for a specific occupational trajectory before entering the human resource market (Gottfredson, 1981). This personalized selection plays a pivotal role in shaping one's prospective career orientation, carrying significant motivational weight (Davey & Stoppard, 1993). Within this context, STEM careers encompass domains such as engineering, healthcare, information technology, and more (Blotnicky et al., 2018). Synthesizing the concepts of STEM careers and career aspirations, STEM career preference can be defined as an individual's inclination or subjective readiness to pursue a future in STEM careers at a specific juncture (Mau & Li, 2018). The career preferences of students serve as a predictive and analytical lens into their future professional paths (Salehjee & Watts, 2015). Consequently, an array of studies has explored and scrutinized the current landscape of STEM career aspirations across students of varying ages, with a focus on three primary spheres. The first domain centers on investigating the present landscape of students' inclinations towards STEM careers. For instance, Koyunlu Ünlü and Dökme (2020) gauged the level of interest among Turkish secondary school students in STEM careers, employing the STEM Career Interest Survey (STEM-CIS) devised by Kier et al. (2014). The second realm delves into the principal factors influencing students' attraction to STEM careers. Cheng et al. (2021), for instance, integrated 3D printing into STEM learning and examined its influence on students' inclinations towards STEM careers. Similarly, Luo et al. (2021) probed the impact of stereotypes surrounding STEM careers on upper primary school students, highlighting the mediating roles of self-efficacy and outcome expectations. Moreover, So et al. (2020) explored the potential effects of elementary school students' perceptions of STEM careers on their interest in the field. The third domain revolves around the implementation of specific methods aimed at fostering students' fascination with STEM careers. Chen (2022) and others adopted an approach involving hands-on STEM activities to heighten interest among elementary students in STEM careers.

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STEM Self-Efficacy, STEM Value Perception, STEM Learning Interest, and STEM Career Preference

Students' value perception of a career refers to the individual's expectation of the likelihood of success in developing a career with this career as well as the values that are identified with the career (Compeau, 2016). An individual's motivation to pursue a particular career is determined by his value perception of that career (Salehjee & Watts, 2015). The easier an individual perceives himself to be valued in this occupation, the more likely he/she is to be motivated and thus the more motivated he/she is to pursue that occupation (Nugent et al., 2015; Zhang & Barnett, 2015). Prior research has found that students' perceptions of value in STEM careers can had an impact on students' STEM career expectations (Blotnicky et al., 2018; Heilbronner, 2009; Luo et al., 2021). However, despite the relationship between the two, few studies have explored how students' perceived STEM values influence their career preferences towards STEM.

Learning interest is a fundamental motivator and driver of learning (Dewey, 1913; Hidi & Renninger, 2006). In this study, STEM learning interest refers to students' interest in learning STEM-related courses. Students' interest in learning a subject is a key predictor of future participation in related careers (NRC, 2007). Currently, there are many studies that have examined the influence of students' interest in STEM learning toward career preference, confirming that students' interest in STEM learning is a significant positive predictor of students' occupational dispositions (DeBacker & Nelson, 1999), and that students' learning interest is a positive predictor of students' self-efficacy (Jiang et al., 2022). In addition, self-efficacy has been also shown to play an important mediating role in STEM education (Cabell, 2021, Halim et al., 2021).

Research Questions and Hypotheses

In order to clarify how the STEM value perception influence the STEM career preference of university students majoring in agriculture and forestry, and then to better enhance students' STEM career preference, this study posed the following research question:

1. How does the perception of STEM value (VP) among undergraduate students majoring in agroforestry impact their preferences for STEM careers (CP)?
2. What underlying mechanisms drive this influence, and how do STEM learning interest (LI) and STEM self-efficacy (SE) contribute to the pathway through which STEM value perceptions (VP) shape STEM career preferences (CP)?

To answer the research question, below hypotheses were made about the influence mechanisms between the independent and dependent variables based on the existing literature.

H1: Agroforestry students' STEM value perceptions (VP) can directly influence students' STEM career preferences (CP);
H2: Agroforestry students' STEM value perceptions (VP) can influence STEM career preferences (CP) by influencing STEM learning interest (LI);
H3: Agroforestry students' STEM value perceptions (VP) can influence STEM career preferences (CP) by influencing STEM self-efficacy (SE);
H4: There is a chain effect between STEM value perceptions (VP), STEM learning interest (LI), STEM self-efficacy (SE), and STEM career preferences (CP) of agroforestry students.

The hypothetical model for this study is shown in Figure 1.

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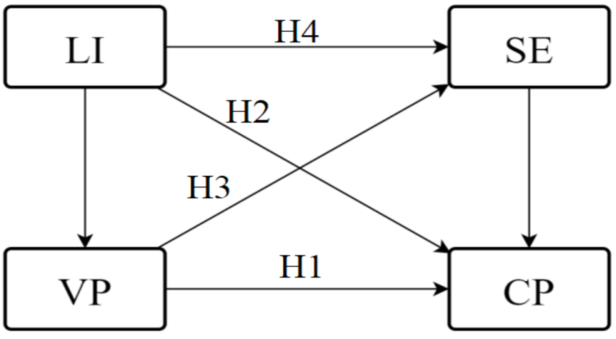
Figure 1
Hypothetical Model



Research Methodology

Background

This research employed a quantitative research methodology, specifically utilizing Structural Equation Modelling (SEM), to explore the influences among STEM value perceptions, STEM learning interest, STEM self-efficacy, and STEM career preferences within the context of students majoring in Agriculture and Forestry. The study employed a standardized questionnaire to collect data. Prior to the main survey, a preliminary test was conducted with a subset of participants, which facilitated the refinement of the questionnaire through Confirmatory Factor Analysis (CFA) and reliability analysis. The final survey took place in March 2023, and an electronic distribution method was employed to administer the questionnaire to the entirety of students enrolled in agricultural and forestry programs at Zhejiang Agriculture and Forestry University, China. The coordination of this process was overseen by class lecturers, and the data collection spanned approximately one month. Subsequent to collecting the completed questionnaire, a rigorous analysis was undertaken employing statistical tools such as SPSS and Amos. The primary goal of this analysis was to uncover the extent to which students' perceived values in STEM education influence their preferences for STEM careers. Additionally, the study sought to elucidate the underlying mechanisms that mediate this connection and rigorously test the research hypotheses.

Participants

To ensure a balanced representation, accuracy, and ease of sample collection, a purposive sampling method was employed to survey students from agriculture and forestry universities. Zhejiang Agriculture and Forestry University, dedicated to education and research in these fields, offers a diverse range of programs encompassing agricultural and forestry sciences. Furthermore, the university attracts students from various backgrounds and regions, which also guarantees the collection of a comprehensive and expansive sample.

The formal questionnaire encompassed students from diverse academic years (freshmen to seniors), with ages ranging from 17 to 23 and an average age of 19. The distribution of the online questionnaire facilitated tracking of the respondents' count, culminating in a total count of 1610 responses. The questionnaire was disseminated under the supervision of lecturers, and the electronic format included mandatory questions that needed to be answered comprehensively before submission. This meticulous approach led to a higher level of diligence and completion, consequently resulting in a minimal number of invalid responses. Finally, 1,604 (99.6%) valid questionnaires were identified. Table 1 presents the demographic characteristics of the participants involved in the data collection process.

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Table 1
Demographics of the Participants

Variables		Participants	Percentage (%)
Gender	Male	577	36
	Female	1027	64
Major	Agronomy	113	7
	Plant Protection	76	4.7
	Smart agriculture	18	1.1
	Forestry	170	10.6
	Biotechnology	75	4.7
	Ecology	70	4.4
	Agricultural Resources and Environment	178	11.1
	Horticulture	140	8.7
	Landscape Architecture	209	13
	Agricultural and Forestry Economic Management	115	7.2
	Animal Science	31	1.9
	Veterinary medicine	58	3.6
	Facility Agricultural Science and Engineering	86	5.4
	Tea science	36	2.2
	Cultural Industry Management (Tea Culture)	54	3.4
	Traditional Chinese Medicine	94	5.9
	Biopharmaceuticals	81	5
Grade	Freshman	615	38.3
	Sophomore	490	30.5
	Junior	288	18.0
	Senior	211	13.2

Instrument

This study formed a questionnaire on students' STEM learning interest, STEM self-efficacy, STEM values perceptions, and STEM career preferences consisting of four sub questionnaires. The instrument contains a total of 14 items with a 5-point Likert scale (1=strongly agree, 2=agree, 3=neutral, 4=disagree, 5=totally disagree). The specific distribution of the questionnaire items is shown in Table 2.

Table 2
Distribution of the Questionnaire Items

Sub-questionnaire	Item
STEM Learning Interest	1, 2, 3, 4
STEM Self-Efficacy	5, 6, 7, 8
STEM Value Perception	9, 10, 11, 12
STEM Career Preference	13, 14

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The STEM Learning Interest sub-questionnaire was structured into four distinct dimensions, mirroring interest in knowledge comprehension, engagement in activity participation, focus on skill acquisition and enthusiasm for course learning. Each dimension was represented by a singular item, inspired by the work of McGuire et al. (2021). Regarding the STEM Self-Efficacy sub-questionnaire, following the questionnaire's development and validation by Luo et al. (2021), students' STEM self-efficacy was categorized into four facets: understanding of knowledge, mastery of skills, aptitude for problem solving, and performance in tests. Each of these sections corresponded to an individual item. As for students' perceptions of STEM value, guided by the research of Halim et al. (2018), it was compartmentalized into four dimensions: recognition within society, economic standing, prospects for employment, and personal ability enhancement. A set of questions was designated for each dimension to capture students' perspectives. To gauge students' career inclinations, the study drew inspiration from Karen et al.'s (2018) research. Specifically, two questions were employed: "In my future career, I will utilize knowledge linked to mathematics, science, engineering, and technology to resolve challenges" and "I possess a keen interest in pursuing a career as a scientist, engineer, or technologist." These questions provided insights into students' preferences for STEM-related career paths.

In this study, the main factors were measured in the form of sub-questionnaires, so testing the quality of the measured data is an important prerequisite to ensure that the subsequent analysis is meaningful. First, the internal consistency of the scales was tested by the Cronbach reliability coefficient. As shown in Table 2, the reliability coefficient values of the sub-questionnaires are all above 0.8, and the instrument has good reliability. In addition, the Confirmatory Factor Analysis (CFA) model fit sub-questionnaire of STEM learning interest, STEM self-efficacy and the STEM career preferences was also required. The CFA was used to judge the model fit mainly by referring to χ^2/df, RMR, RMSEA, CFI and other indicators. Among them, the cardinality freedom ratio is always greatly influenced by the sample size, therefore, in large samples, it is usually combined with other indicators for comprehensive evaluation. The results of model fitness tests for the subscale of STEM learning interest, STEM self-efficacy and the STEM career preferences are shown in Table 4. It can be seen that each indicator basically meets the requirements, and the model has an acceptable fitness.

Table 3
Reliability of the Sub-questionnaires

Sub-questionnaire	Cronbach's α	Items
LI	.928	4
SE	.948	4
VP	.884	4
CP	.837	2
Total	.948	16

Table 4
Model Fit

Sub-questionnaire	GFI	AGFI	RMSEA	NFI	RFI	IFI	CFI	RMR	χ^2/df
LI	.999	.993	.026	.999	.998	1.000	1.000	.004	2.072
SE	.995	.974	.069	.997	.992	.998	.998	.006	7.662
VP	1.000	.999	.001	1.000	1.000	1.000	1.000	.001	.195
Reference Value	> .9	> .9	< .1	> .9	> .9	> .9	> .9	< .1	<10

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Based on the goodness of fit, convergent validity (Average Variance Extracted, AVE) and composite reliability (CR) were further examined. The standardized factor loadings of each item in the corresponding dimension were calculated by the established CFA model. The AVE and CR values were calculated. The CR > 0.8 and the AVE > 0.5 (Table 5), which proves that the convergent validity and combined reliability are good.

Table 5
AVE and CR Results

Path			β	AVE	CR
LI1	<---	LI	.854	.764	.928
LI2	<---	LI	.894		
LI3	<---	LI	.890		
LI4	<---	LI	.858		
SE1	<---	SE	.865	.821	.948
SE2	<---	SE	.918		
SE3	<---	SE	.927		
SE4	<---	SE	.912		
VP1	<---	VP	.823	.661	.886
VP2	<---	VP	.790		
VP3	<---	VP	.865		
VP4	<---	VP	.770		
CP1	<---	CP	.863	.722	.838
CP2	<---	CP	.836		

Ultimately, as depicted in the findings presented in Table 6, the discriminant validity assessment highlights that the standardized correlation coefficient between each pair of sub-scales remains below the square root of the corresponding dimension's value. This outcome underscores the robustness of discriminant validity among all sub-questionnaires, signifying that each sub-questionnaire effectively distinguishes itself from others within the construct.

Table 6
Discriminant Validity Test

Subscale	LI	SE	VP	CP
LI	.764			
SE	.814	.821		
VP	.581	.537	.661	
CP	.835	.766	.679	.722
AVE square root	.874	.906	.813	.850

Data Analysis

Following the collection of data, an analysis was performed employing SPSS 27.0 and Amos 27.0. The initial steps encompassed reliability assessments, validity analyses for confirmation, evaluations of convergent validity, combined reliability measurements, and differential validity tests. These evaluations aimed to ascertain that the indicators adhered to the prescribed model fit standards. The research subsequently proceeded to examine the

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interconnections among students' STEM learning interest, STEM self-efficacy, STEM value perceptions, and STEM career preferences. In this analysis, STEM value perceptions served as the independent variables, while STEM learning interest and STEM self-efficacy functioned as mediating variables. The primary focus was on STEM career preference as the dependent variable. This examination encompassed the calculation of both the direct impact of STEM value perceptions on STEM career expectations and their indirect influence via STEM learning interest and STEM self-efficacy pathways.

Research Results

Descriptive Statistics and Normality Test

Descriptive statistical analysis and normality tests were conducted on the overall student performance, and the results are shown in Table 7. According to the results of the overall descriptive statistical analysis, it can be seen that the mean score of each Subscale is between 3 and 4. This shows that college students in agriculture and forestry as a whole had above-average levels of STEM learning interest, STEM self-efficacy, STEM value perception, and STEM career preferences. The highest mean value of the four elements is the STEM value perception, which indicates that students all believed that knowledge related to STEM subjects had some value. Also, the lowest is STEM self-efficacy, indicating that students' confidence in their ability to master learning and activities related to STEM subjects needs to be further improved.

In addition, for each item, a normality test was conducted using kurtosis and skewness. The kurtosis coefficients of the data in this study are within 3 in absolute value and the skewness coefficients are within 8 (Table 7), indicating that the measured items met the approximate normal distribution.

Table 7
Descriptive Statistics and Normality Test

Subscale	Item	*M*	*SE*	Skewness	Kurtosis	*M*	*SD*
LI	LI1	3.08	1.006	- .290	- .068	3.155	3.610
	LI2	3.05	.998	- .242	- .194		
	LI3	3.23	.993	- .441	- .028		
	LI4	3.26	.983	- .429	.072		
SE	SE1	3.13	.967	- .356	- .020	3.123	3.584
	SE2	3.09	.974	- .310	- .002		
	SE3	3.19	.954	- .414	.115		
	SE4	3.08	.960	- .265	.023		
VP	VP1	3.56	.912	- .776	.872	3.55	3.134
	VP2	3.64	.912	- .872	1.026		
	VP3	3.51	.898	- .633	.756		
	VP4	3.47	.916	-.656	.658		
CP	CP1	3.21	1.008	- .360	- .038	3.18	1.911
	CP2	3.15	1.052	- .270	- .271		

Correlation of STEM Learning Interest, STEM Self-Efficacy, STEM Value Perception and STEM Career Preferences

Pearson correlation analysis was conducted on the scores of four sub-questionnaires: students' STEM value perception, STEM learning interest, STEM self-efficacy, and STEM career preferences. Exploratory analysis of the correlations among multiple variables shows that the correlation coefficients r between each variable are greater than 0 and all are significant (Table 8). This indicates that there was a significant positive correlation between students' STEM value perception, students' STEM learning interest, STEM self-efficacy, and STEM career preferences supporting further regression analysis and mediation effect tests.

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Table 8
Pearson's Correlation Coefficient Between Sub-questionnaires

	LI	SE	VP	CP
LI	1			
SE	.766**	1		
VP	.541**	.502**	1	
CP	.739**	.683**	.588**	1

**. Significant correlation at the .01 level (two-tailed).

Path Hypothesis Testing

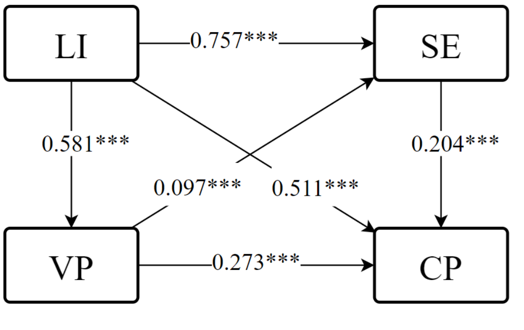
The path hypothesis of the model was tested, and the data obtained are shown in the table. As can be seen from Table 9, the p-values are less than .001 for each path of the model, indicating that there was a significant positive predictive relationship between the independent variables on the dependent variable. That is, students' interest in STEM learning, perceptions of STEM values, and STEM self-efficacy all significantly and positively predicted students' STEM career preferences.

Table 9
Direct Effects Test

Path			*β*	*S.E.*	*C.R.*	*p*
LI	→	VP	.581	.033	21.147	***
SE	→	LI	.757	.026	29.703	***
SE	→	VP	.097	.028	4.335	***
CP	→	LI	.511	.038	14.034	***
CP	→	SE	.204	.033	6.104	***
CP	→	VP	.273	.029	11.458	***

Based on the results of the hypothesis test, the path is derived as shown in Figure 2.

Figure 2
Path Testing



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The total influence of students' STEM value perceptions on students' STEM career preferences was tested with a confidence interval of [0.3345, 0.3828] without 0 and an effect size of 0.3587, indicating that students' value perceptions of STEM had a significant predictive effect on STEM career preferences (Table 10). After that, the mediating variables of students' STEM learning interest and STEM self-efficacy were added for testing, at which point the confidence interval of students' perceptions of STEM values on students' STEM career preferences is [0.0114, 0.1224], which do not contain 0, indicating a significant direct effect. The confidence interval for the total indirect effect is [0.0126, 0.1895], which does not contain 0, indicating that the total indirect effect was significant, and the mediating effect existed and was partially mediated. The amount of total indirect effect accounts for 59.63% of the total effect. The indirect effects were divided into three paths, none of which confidence intervals contain 0, indicating that the mediating effect of STEM learning interest, the mediating effect of STEM self-efficacy, and the chain mediating effect of STEM learning interest and STEM self-efficacy all held true.

Table 10
Bootstrap Analysis of Mediation Effects

Path	*β*	*S.E.*	Bootstrap 95% CI		*p*
			Lower	Upper	
Total Effect	.3587	.0123	.3345	.3828	Significant
Direct effect	.1447	.0114	.1224	.1670	Significant
Total Indirect Effect	.2139	.0126	.1895	.2383	Significant
Path 1: VP ⟶ LI ⟶ CP	.1428	.0121	.1196	.1169	Significant
Path 2: VP ⟶ LI ⟶ SE ⟶ CP	.0176	.0042	.0103	.0264	Significant
Path 3: VP ⟶ SE ⟶ CP	.0536	.0077	.0391	.0695	Significant

Discussion

This study examined the influence of STEM value perceptions of university students majoring in agriculture and forestry on their STEM self-efficacy, STEM learning interest and STEM career preference. A sample of 1604 agriculture and forestry students from the first to fourth year of university was chosen to be analyzed with their STEM value perception as the independent variable, STEM career preference as the dependent variable, and STEM learning interests and STEM self-efficacy as mediating variables.

The results underscore that students' STEM value perceptions possess a direct influence over their preferences for STEM careers. Previous research has revealed that heightened STEM career knowledge correlates with an increased likelihood of selecting STEM professions among secondary school students (Blotnicky et al., 2018; Drymiotou et al., 2021). Additionally, STEM stereotypes can predict the interest secondary school students show in STEM careers (Shen et al., 2014), while there are noteworthy implications on primary school students' perceptions and interest in STEM careers (So et al., 2020). This study extends these previous findings by delving deeper into the domain of college students majoring in agriculture and forestry. It specifically shows how the perceived value of STEM-related knowledge influences the likelihood of such students opting for STEM careers. This research reinforces the significance of STEM value perceptions in shaping career aspirations within this student demographic. Given the historical trend of agriculture and forestry majors facing lower popularity, coupled with the prevalent belief that career prospects in these fields are limited, it becomes pivotal to educate these students about their career options upon enrollment, clarifying the value and potential trajectories that their chosen major can offer (Drymiotou et al., 2021).

Furthermore, this study demonstrates that STEM value perceptions can influence students' pursuit of STEM careers through their impact on STEM learning interest and STEM self-efficacy. This correlation aligns with prior research indicating that students' interest in learning and their perceived self-efficacy significantly impact their expectations for STEM careers (Brown et al., 2016; Lent et al., 2018; Potvin & Hasni, 2014). It is also consistent with

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findings showing that students' perceptions of STEM values can indirectly influence their self-efficacy and, in turn, their career expectations (Garriott et al., 2017; Luo et al., 2021). Building upon this foundation, the present study not only validates the role of STEM value perceptions in shaping STEM learning interest and self-efficacy but also unveils a chain mediating effect encompassing STEM value perceptions, STEM learning interest, STEM self-efficacy, and STEM career preferences.

The identified chain effect highlights that when students perceive a specific piece of knowledge as valuable, their interest in learning it amplifies, fostering greater enthusiasm and self-efficacy for mastering the subject. Consequently, this heightened self-efficacy drives their career expectations linked to that particular field of knowledge (Cromley et al., 2016; Hidi & Renninger, 2006; Liu et al., 2022). As a result, educators hold the potential to enhance students' inclinations toward STEM careers by focusing on elevating their perceptions of the value of STEM. This, in turn, can stimulate greater interest in STEM-related courses and bolster students' confidence in their ability to excel in these areas.

Conclusions and Implications

This study aimed to explore the influence of STEM values perceptions on the STEM career preferences of undergraduates majoring in agriculture and forestry. Through SEM analysis and mediation effect analysis, it has been found that students' STEM values perceptions directly influence students' STEM career preferences, as well as influence students' career preferences by influencing their STEM learning interests and STEM self-efficacy, and there is also a chain-mediated effect between students' STEM values perceptions, STEM learning interests, STEM self-efficacy and STEM career preferences. The results extended previous research that did not identify factors influencing STEM career dispositions among agroforestry students at college and university and highlighted the importance of professional perceptions in students' future career choices, as well as the important mediating role of enhancing students' interest in learning and self-efficacy. Therefore, a few suggestions are provided for teachers to cultivate students' STEM career preferences in the future. Firstly, teachers should pay attention to creating informal learning environments, such as extracurricular activities, to stimulate students' interest in STEM learning when conducting teaching. Second, teachers should pay attention to improving students' knowledge transfer and application abilities, cultivating students' problem-solving skills, and helping students to improve their sense of self-efficacy. In addition, in the future, educators should pay more attention to students' perception of STEM values, actively carry out career education, and help agricultural and forestry majors to improve their perception of career values and their sense of professional and occupational identity.

There are some limitations in this study, due to time and other limitations, there are many factors influencing students' career preferences, this study only chose students' STEM value perceptions, STEM learning interest and STEM self-efficacy for the study, and didn't add the family background and other factors, in addition, in the spirit of the principle of convenience sampling, this study into the selection of a province of agriculture and forestry majors for the survey, in the future, the STEM career tendency of students majoring in agriculture and forestry in other provinces will be explored.

Declaration of Interest

The authors declare no competing interest.

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Appendix

Survey for STEM Career Preference, Learning Interest, Self-Efficacy, and Value perception of Agroforestry Undergraduates

Dear Student,

Thank you for participating in this survey, which is designed to get a basic picture of your interest in STEM (Science, Technology, Engineering and Mathematics) related subjects and your views on STEM related careers. The questionnaire is anonymous responses and is for research use only, so you can feel free to fill it out, and I hope you will follow your heart's true thoughts and fill it out carefully, thank you!

LI1 Learning knowledge about Science, Technology, Engineering and Mathematics is interesting
A totally disagree, B disagree, C neutral, D agree, F strongly agree

LI2 I enjoy completing tasks related to science and engineering courses
A totally disagree, B disagree, C neutral, D agree, F strongly agree

LI3 The Science, Technology, Engineering and Mathematics related courses I take are relevant to my life
A totally disagree, B disagree, C neutral, D agree, F strongly agree

LI4 I am curious about discoveries made during activities and events related to Science, Technology, Engineering and Mathematics
A totally disagree, B disagree, C neutral, D agree, F strongly agree

SE1 I think I am capable of solving problems encountered in my Science, Technology, Engineering and Mathematics studies

A totally disagree, B disagree, C neutral, D agree, F strongly agree

SE2 I am confident that I can perform well in learning knowledge related to Science, Technology, Engineering and Mathematics
A totally disagree, B disagree, C neutral, D agree, F strongly agree

SE3 I believe I can acquire skills related to Science, Technology, Engineering and Mathematics courses and experiments
A totally disagree, B disagree, C neutral, D agree, F strongly agree

SE4 I am confident that I can do well in exams related to Science, Technology, Engineering and Mathematics courses
A totally disagree, B disagree, C neutral, D agree, F strongly agree

VP1 Professions in Science, Technology, Engineering and Mathematics enjoy a high level of social prestige
A totally disagree, B disagree, C neutral, D agree, F strongly agree

VP2 Occupations in Science, Technology, Engineering and Mathematics have higher earnings
A totally disagree, B disagree, C neutral, D agree, F strongly agree

VP3 Jobs in Science, Technology, Engineering and Mathematics have more employment opportunities
A totally disagree, B disagree, C neutral, D agree, F strongly agree

VP4 If I work in Science, Technology, Engineering and Mathematics jobs, I can improve my teamwork skills, problem solving skills, etc.
A totally disagree, B disagree, C neutral, D agree, F strongly agree

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CP1 I will use knowledge of Science, Technology, Engineering and Mathematics to solve problems in my future career.
A totally disagree, B disagree, C neutral, D agree, F strongly agree

CP2 I am interested in becoming a scientist, engineer or technologist
A totally disagree, B disagree, C neutral, D agree, F strongly agree

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UTILIZATION OF PROCESS DATA IN CHINA: EXPLORING STUDENTS' PROBLEM-SOLVING STRATEGIES IN COMPUTER-BASED SCIENCE ASSESSMENT FEATURING INTERACTIVE TASKS

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Abstract. *Students' problem-solving strategies and the differences among strategy groups were explored by analyzing the process data collected during student interactions with computer-based science items. Data were gathered from 1516 eleventh-grade students from 4 schools in China. Analyses of the sequences of students' response actions revealed that the students were divided into four strategy groups when designing experiments to solve scientific problems: the scientific and rigorous strategy (18.5%), scientific and less rigorous strategy (25.4%), incomplete strategy (31.5%), and chaotic strategy (24.6%). The heatmaps of response actions for each strategy and the frequencies of the most representative response sequences were further explored to understand the students' detailed trajectories. The results showed that successful problem solvers were generally inclined to explore all possibilities of experimental combinations and design experiments scientifically and rigorously based on the relevant scientific principles. Moreover, the timestamps of response actions were explored to show that the students who adopted the scientific and rigorous strategy spent more time seeking solutions, suggesting that students may need sufficient time to solve complex and authentic scientific problems. The findings enrich the literature on using process data to address theoretical issues in educational assessment and provide students with individualized instructional needs for teachers to improve students' scientific problem-solving competency.*
Keywords: *process data, scientific problem-solving, computer-based assessment, China*

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Introduction

The rapid growth of science and technology has led to fundamental and momentous changes in the societies of the 21st century. These changes are reflected in the types and complexities of problems encountered in everyday life. To successfully address these problems, problem-solving competency that focuses on in-depth exploration, critical thinking, and analytical reasoning in the process of understanding and applying knowledge is necessary and crucial for individuals (Lavoie, 1993; NRC, 1996). Problem-solving competency is an essential foundation for students to actively participate in social activities and engage in meaningful learning in the 21st century (NRC, 2010; OECD, 2013). The ability to solve real-world problems is a crucial component of scientific literacy and a significant goal of science education (NRC, 1996; NRC, 2012). Scientific problem-solving competency can help students construct a systematic knowledge structure and fully apply knowledge to cope with the challenges caused by the rapid development of science and technology (Friege & Lind, 2006; NRC, 1996).

To better cultivate students' ability to solve scientific problems, the processes of solving problems and students' struggles to seek solutions need to be explored. Recently, computer-based assessments that support human-computer interaction have emerged in various problem-solving domains (Jiang et al., 2021; Vendlinski & Stevens, 2002). Computer-based assessments record detailed interactions between the problem solver and the task environment and thereby capture salient solution processes (Chung & Baker, 2003; Provasnik, 2021). The rich process data generated from the interactive items reflect the processes of answering the items and provide tremendous opportunities to reveal the cognitive and behavioral processes of the problem solvers. A growing number of studies have focused on process data to reflect students' cognitive processes during problem solving. For

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example, some attempts have been made to explore the patterns of log files obtained from the National Assessment of Educational Progress (NAEP) and the Programme for International Student Assessment (PISA) (Bergner & von Davier, 2019; Greiff et al., 2015).

However, it is still challenging to derive specific implications from the behavioral patterns found in log files because the cognitive process during problem solving is a black box and it is difficult to make sense of the hundreds of pieces of information students produce when solving problems in computer-based assessments (Greiff et al., 2015). Therefore, further exploration of process data is necessary to obtain more substantial findings, which can inform teachers and policymakers about students' cognitive processes during problem solving. Meanwhile, limited research has been performed to emphasize the implementation of independently developed interactive assessments in China and the exploration of Chinese students' cognitive processes of scientific problem solving. Hence, process data were utilized to explore cognitive strategies that eleventh-grade students adopt when solving interactive scientific tasks developed in China.

Literature Review

Scientific Problem-solving Competency

Problem-solving competency determines how successful an individual will be at finding solutions to challenges in life (Lazakidou & Retalis, 2010; OECD, 2013). Mayer proposed a widely accepted viewpoint that problem solving is the cognitive process of transforming a given situation into a target situation when there is no obvious solution (Mayer, 1992). The PISA 2012 problem-solving framework also stated that problem-solving competency is the ability of an individual to transform a given problem situation into a target situation by understanding the problem and solving it when the solution is not obvious and the individual's emotional willingness to participate in the problem solving (OECD, 2013). Hence, researchers emphasize that problem solvers explore the paths of solving problems from the initial state to the final goal state. Problem solving is a complicated process filled with continuous exploration from an initial state to a target state, which may involve multiple cognitive and emotional variables (OECD, 2013; Reid & Yang, 2002).

Consistent with the aforementioned viewpoints, researchers have stated that problem solving in the field of science education is a process of scientific inquiry to some extent (Gayford, 1989). Students need to have some scientific knowledge and process skills to solve scientific problems successfully (Chang et al., 2007). The process of solving scientific problems involves the generation and explanation of ideas (Chang & Weng, 2002). Students need to think divergently to seek solutions to solve problems and need to explain and evaluate various solutions to choose the final one. Although researchers have considered scientific problem-solving competency from various perspectives, they are generally aware that scientific problem solving is a process of inquiry that requires a series of scientific process skills. Therefore, scientific problem-solving competency in this study involves using a series of scientific process skills combined with scientific knowledge to seek solutions and evaluate them to solve complex problems relevant to science and technology in daily life.

Assessment Framework for Scientific Problem-solving Competency

Researchers have stated that there is domain-general problem solving that pays attention to problem situations across domains and domain-specific problem solving that focuses on specific educational areas, such as mathematics and science (Greiff & Neubert, 2014; Sternberg, 1995; Sugrue, 1995). Although the scientific problem-solving competency in this study is domain-specific problem solving, the studies of domain-general problem solving have also been instructive for us to consider our assessment framework because the two lines of research show considerable overlap. One of the most well-known assessments in the area of problem solving is the PISA 2012, which utilized a framework for domain-general problem solving (Greiff et al., 2014). This framework underlines a computer-based test design in which the students need to deal with daily real-life problems such as configuring an MP3 player. Students must explore and understand the problem situation (exploring and understanding), represent the problem by constructing representations, formulate hypotheses by identifying the relevant factors in the problem (representing and formulating), devise and carry out a plan to reach the goal state (planning and executing), monitor their progress and reflect on solutions from various perspectives (monitoring and reflecting) (OECD, 2013). Therefore, problem-solving competency involves formulating a hypothesis, devising and carrying

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out a plan to solve the problem, and monitoring and critically evaluating problem-solving solutions, which are attributes of scientific inquiry.

Some studies put problem solving in a special, domain-specific domain based on its context. Polya originally proposed a four-stage problem-solving model and revised it in mathematics education, including understanding the problem, devising a plan, trying and carrying out the plan, and monitoring and reflecting on the solution (Polya, 1957). The four-stage problem-solving model is consistent with the problem-solving framework in the PISA 2012 to some extent. After Polya, some studies developed a problem-solving framework and assessment in the field of science. Some researchers have proposed that problem solving in science education has four overlapping and interactive aspects: problem posing, problem approaches, problem solutions, and communication (McIntosh, 1995). Problem posing includes extracting a science problem from a realistic situation, making or revising a hypothesis, and planning experiments. Problem approaches involve controlling variables in an investigation, collecting appropriate data, and revising approaches when warranted by new evidence. Problem solutions include developing various solutions to the same problem, comparing the results, and making conclusions based on data. Communication focuses on communicating procedures, interpretations, and thinking pathways. Hence, the scientific problem-solving process has obvious scientific inquiry attributes and involves various scientific process skills (Eysenck & Keane, 2000; Gayford, 1989; Ross & Maynes, 1983). Moreover, scientific discovery as dual search (SDDS), an important model utilized to explain the process of scientific problem solving (Schauble, 2003), perceives scientific problem solving as a coordinated search in two problem spaces, the hypothesis space and experiment space (Klahr & Dunbar, 1988). In the hypothesis space, the initial state is domain knowledge, and the target state is hypotheses. Search in the experiment space is directed toward experiments that discriminate between rival hypotheses and yield interpretable outcomes (Eysenck & Keane, 2000). It is obvious that scientific problem solving is a process of scientific inquiry to some extent (Gayford, 1989). Based on what scientists do when designing experiments and solving scientific problems, problem solving involves various skills, including formulating hypotheses, designing experiments, recording information, and judging the data collected (Ross & Maynes, 1983). Researchers' emphasis on experimental problem solving further indicates that the design of inquiry experiments is a crucial component of scientific problem-solving competency.

Reasoning is another component of scientific problem-solving competency. Educational researchers in the earth and space sciences claim that problem-solving skills include domain-specific knowledge, reasoning skills, and attitudes (Chang et al., 2007). Researchers in chemistry state that reasoning ability is highly related to students' ability to solve stoichiometric problems successfully (Robinson & Niaz, 1991). The PISA2012 problem-solving assessment framework also clearly puts forward the importance of reasoning, arguing that problem-solving processes rely on one or more reasoning skills (OECD, 2013). Additionally, explanations for problem solutions necessary for evaluating proposals are perceived as another component of scientific problem-solving competency. Studies suggest that problem solvers tend to articulate the steps to a problem solution and why they choose this solution (Chang & Weng, 2002; Chi et al., 1994). Successful problem solvers produce self-explanatory and principle-based explanations to effectively relate the solution to the principles or knowledge in science (Camacho & Good, 1989).

Three components, including the design of scientific inquiry, scientific reasoning, and scientific explanation, are perceived as crucial dimensions in the assessment framework for scientific problem solving in this study.

Use of Process Data to Reflect Students' Cognitive Processes in Computer-based Assessments

It is essential to understand the students' cognitive processes in solving scientific problems and to identify students who are struggling with these processes for further instruction (Bergner & von Davier, 2019; Greiff et al., 2015). With the conversion of science assessments from paper-and-pencil to computerized formats, process data derived from interactive item types emerged (Jiang et al., 2021; Provasnik, 2021). Log files are data sources for process data that reflect the cognitive and metacognitive processes involved in completing test tasks (Provasnik, 2021). Process data provide fine-grained information about how students plan, select, and execute various problem-solving strategies to find a solution. Therefore, the crucial role of process data is to delineate how students solve problems, not just whether they do. Especially when process data are combined with theoretical frameworks and response data, abundant opportunities are afforded to study problem solvers' paths to a solution (Provasnik, 2021).

Process data mainly include detailed records of student interactions with the computer system, such as action sequences when solving simulation-based science tasks, answer change behaviors, and the timestamps of these actions (Bergner & von Davier, 2019). For computer-based science assessment focusing on interactive tasks, an

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important piece of process data is the sequences of problem solvers' response actions. These sequences provide insights into the strategies problem solvers frequently apply to solve scientific problems. For example, researchers exploited log files containing the process data of problem-solving behavior obtained from the 2012 cycle of the PISA (Greiff et al., 2015). Log-file analyses were conducted to explore whether the vary-one-thing-at-a-time (VOTAT) strategy that students employed while solving the climate control item was related to their performance and then to identify several groups of students according to their exploration strategies. The classification of response strategies based on the analyses of problem solvers' action sequences is a good way to identify classes of problem solvers and their specific needs (Arslan et al., 2020; Jiang et al., 2021).

Another crucial piece of process data that researchers pay attention to is the timestamps of response actions. Extensive studies have explored total response time on test questions as an indication of motivation (Lee & Jia, 2014; van der Linden, 2008). The timestamp data obtained from NAEP have been used to show the speed at which students compose written responses to test prompts and reflect various patterns and amounts of writing (Bergner & von Davier, 2019; Provasnik, 2021). Moreover, some research indicated that a long response execution time might suggest that the problem solvers are stumped by a problem; a short execution time might represent their high proficiency or rapid guessing (Guo et al., 2016; Lee & Jia, 2014). Other researchers claim that successful problem solvers devote considerable time to understanding the problem situation and seeking solutions (Gong et al., 2020). When constructing solutions to problems, experts generally devote sufficient time to effectively develop a strategy for creating a solution that is different from that of novices, who often approach problems haphazardly (Yerushalmi & Eylon, 2015). The aforementioned conclusions drawn on the analyses of response time are different and even opposite. This study can provide further information about the patterns of students' cognitive processes when solving scientific problems.

Problem Statement

As mentioned earlier, due to the complexity of the scientific problem-solving process, there is much room for improvement in analyzing students' cognitive strategies when solving scientific problems. By categorizing response strategies, categories of problem solvers and their specific needs can be identified, and this provides valuable reference and evidence for educational intervention to improve problem solvers' scientific problem-solving competency (Arslan et al., 2020; Jiang et al., 2021). However, there has been little research on Chinese students' classification of cognitive strategies for solving scientific problems from the perspective of process data. Therefore, the purpose of the present study was to explore the classification of students' experimental design strategies when solving scientific problems and the differences across strategy classes by analyzing process data. Accordingly, this study was conducted by analyzing Chinese students' sequences of actions and response times with a focus on three research questions:

RQ1: What is the classification of experimental design strategies that eleventh-grade Chinese students apply when solving scientific problems?
RQ2: What is the detailed trajectory of each class of experimental design strategies?
RQ3: Is there a significant difference in response time across strategy classes?

Research Methodology

Research Design

The methodology employed in this study was that of a quantitative analysis. The computer-based science assessment was administered to student participants in July 2021, and quantitative data were obtained. Process data including the logs of students' actions and the corresponding timestamps were analyzed. Descriptive statistics and Analysis of Variance (ANOVA) revealed the patterns of students' strategies when solving scientific problems. First, descriptive statistics of students' actions were performed to present a classification of experimental design strategies. Second, descriptive statistics were performed on students' response sequences to reveal the detailed trajectories of each category of experimental design strategies. Finally, to explore the differences in response time across strategy classes, descriptive statistics and ANOVA tests on response time were conducted.

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Participants

In this study, a convenience sample of four high schools from a city (abbreviated as "M") located in southwest China was recruited. The sample schools, including two urban and two suburban schools located in four regions in M city, provide ordinary educational resources to students. All four schools were in the middle rank (top 50.0%) of the education quality in M city. The students who attended the schools could be described as belonging to urban and suburban areas, with the school serving low, middle, and upper-income families. Students in grade eleven from the four sample schools participated in the test at the end of the spring term of the 2020-2021 academic year, which constituted a total sample of 1516 students (57.0% female, 43.0% male). These students were between the ages of 16 and 17. The process data of students' response actions to the inquiry task in subtask 1 of the Handy Freezer (abbreviated as "HF," see Figure 1) task needs to be collected to analyze their problem-solving strategies. This inquiry task requires students to continually click buttons and record the experimental data. Students' response actions were recorded by the computer systems every 100 milliseconds as process data to show the real-time change in students' responses. Eventually, the process data of 1516 students' action sequences and response times were recorded for the analyses.

Instrument

A computer-based scientific problem-solving assessment featuring interactive tasks was developed. Completion of tasks required only basic computer skills such as clicking on virtual buttons and sliders. The assessment instrument was developed based on the aforementioned framework of scientific problem-solving competency containing three elements (design of scientific inquiry, scientific reasoning, and scientific explanation). The instrument included three tasks consisting of several subtasks and covered the subjects of Physics, Chemistry and Biology. The Physics task consisted of five subtasks; the Chemistry task was made up of six subtasks; and the Biology task consisted of six subtasks. The programming tool JavaScript was utilized to form tasks, and the tasks were embedded in the test system OpenCT (https://open-ct.com). OpenCT is an interactive evaluation system based on Metaverse and educational big data for assessing higher-order thinking skills. The tasks were developed by a research team of three researchers (the first, third and fourth authors) and two technicians. Two of the three researchers were skilled in designing tasks associated with scientific literacy assessment. The other researcher was proficient in assessment theory. The two technicians were adept at designing interfaces for interactive tasks. One task was original and belonged to biology. The other task, belonging to physics, was adapted from an item developed by a research group from Guangxi Normal University. This item was included in a large-scale paper-and-pencil assessment to assess students' scientific literacy in mainland China. Another task, belonging to chemistry, was retrieved from the work of a research team at the National Taiwan Normal University. The instrument in this study was revised according to the comments from three rounds of student interviews and two rounds of expert reviews. Each round of student interviews included eighteen eleventh-grade students; the first round of expert reviews contained three professors who were good at assessing scientific literacy; and the second round of expert interviews included four skilled professors in designing science tasks. The Cronbach's alpha for this instrument is .863. The comparative fit index (CFI), Tucker-Lewis index (TLI), and root mean square error of approximation (RMSEA) are key indicators of model fitness. The values for validity (CFI= .82, TLI= .80, RMSEA= .08) of this instrument show that the model is a moderate fit (Karadakal et al., 2015).

Students had 60 minutes to complete the test. This study analyzed the process data collected from student interactions with one inquiry task in subtask 1 of the HF task (see Figure 1). The Chinese version of this inquiry task was translated into English for reading convenience. The inquiry task involved assessing the ability to design scientific inquiry included in the framework of scientific problem-solving competency and evaluating students' knowledge on the scientific content area of evaporation in physics. On this task, students were instructed to click the buttons representing the "Water Level" and "Towel Position" to explore the condition for the best refrigeration effect. To solve this task, they needed to (1) click the "Water Level" button, (2) click the "Towel Position" button, (3) click the "Record" button to record the experimental data for the selected combination of "Water Level" and "Towel Position," and (4) continuously explore in this way and draw a preliminary conclusion about the condition for the best refrigeration effect according to the experimental data. Detailed logs of the actions and the corresponding timestamps were recorded in-process data and used for analysis.

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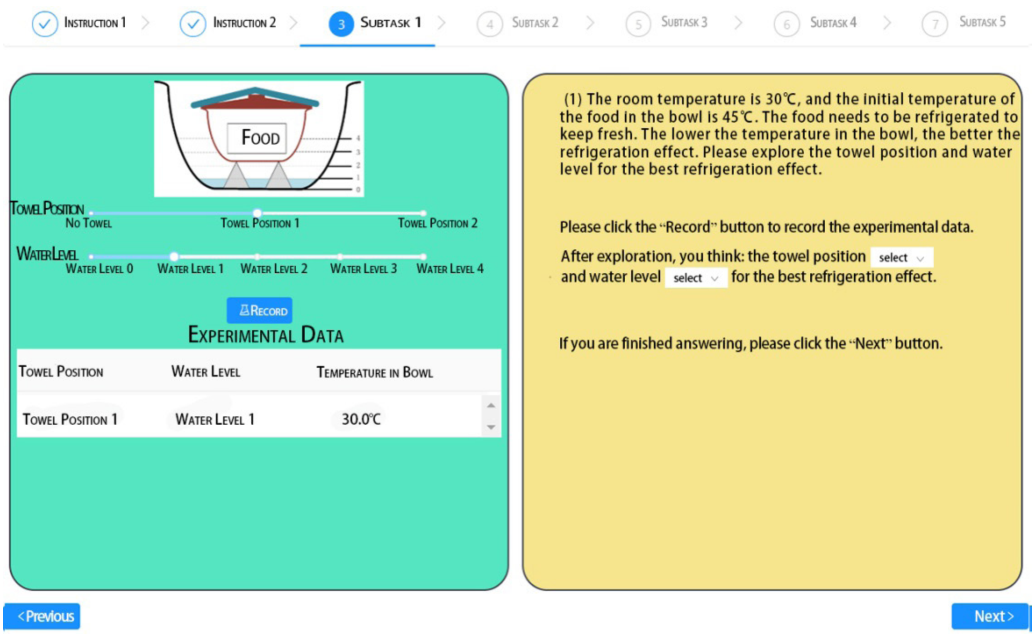
Figure 1
Subtask 1 of a Task Named Handy Freezer



Measures

Response actions. The sequences of actions on the inquiry task in subtask 1 were used to classify the problem-solving strategies according to the principles of designing experiments. The overall numbers of each experimental combination within each strategy group and the frequencies of the most representative response sequences were analyzed to explore the concrete trajectory of each strategy group. In this study, clicking the button representing the "Towel Position" and "Water Level" and recording the experimental data was conceived as a set of response actions recorded as log data. There were three towel positions and five water levels (see Table 1). Specifically, "Towel Position 1" meant the towel covered the lid of the bowl, and "Towel Position 2" meant the towel was long enough to touch the bottom of the bowl. There were fifteen combinations of variables in total (see Table 2). The combination of "Towel Position 2" and "Water Level 2" (code [2, 2]) was the condition for the best refrigeration effect. We classified the problem solvers' response actions based on the principles of designing controlled experiments to better understand students' problem-solving strategies.

Table 1
Variables and Corresponding Codes

Variables	Specific Circumstance	Corresponding Codes
Towel Position	No Towel	0
	Towel Position 1	1
	Towel Position 2	2
Water Level	Water Level 0	0
	Water Level 1	1
	Water Level 2	2
	Water Level 3	3
	Water Level 4	4

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Table 2
Experimental Combinations and Corresponding Codes

Experimental Combinations	Corresponding Codes
No Towel and Water Level 0	[0, 0]
No Towel and Water Level 1	[0, 1]
No Towel and Water Level 2	[0, 2]
No Towel and Water Level 3	[0, 3]
No Towel and Water Level 4	[0, 4]
Towel Position 1 and Water Level 0	[1, 0]
Towel Position 1 and Water Level 1	[1, 1]
Towel Position 1 and Water Level 2	[1, 2]
Towel Position 1 and Water Level 3	[1, 3]
Towel Position 1 and Water Level 4	[1, 4]
Towel Position 2 and Water Level 0	[2, 0]
Towel Position 2 and Water Level 1	[2, 1]
Towel Position 2 and Water Level 2	[2, 2]
Towel Position 2 and Water Level 3	[2, 3]
Towel Position 2 and Water Level 4	[2, 4]

Score. The students' total scores on all three interactive tasks in this assessment and scores on the HF item were indicators of problem-solving ability. To explore the effectiveness of the classification of strategies, total scores on the assessment and scores on HF items were recorded and used for further analysis. Regarding scores on HF items consisting of five subtasks, the full credits for these five subtasks were 1, 8, 8, 1, and 6, respectively. Taking subtask 1 as an example, when one student selected "Towel Position 2" and "Water Level 2" (the correct answer), full credit 1 was given to this student. Additionally, the maximum possible score on the HF item was 24 based on the sum of full credits for five subtasks, and the maximum possible total test score was 76 according to the sum of full credits for all three interactive tasks in this assessment.

Response Time. The time-based measures mainly include the execution time and total response time. Execution time elapsed between the first and the last actions on the inquiry task in subtask 1 of the HF item, reflecting the time needed to perform a mental plan and execute response actions. Total response time is the total time spent on the HF item.

Data Analysis

Quantitative analyses, including descriptive statistics and ANOVA tests, were carried out to address the three research questions. Descriptive statistics were conducted to compare the aforementioned process-related measures across strategy groups. It should be noted that the data of the numbers of clicks for each experimental combination for each strategy group were generated into a two-dimensional array format via Python, and then the Matplotlib Library was applied to visualize data to heatmaps. To validate the classification of strategy groups, ANOVA tests on total test scores and HF item scores were conducted via the IBM Statistics SPSS 24.0 software. To explore the potential differences in the problem-solving processes among students using different strategies, the ANOVA tests were performed on the categorical variables (e.g., total response time, execution time).

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Research Results

Classification of Experimental Design Strategies

When designing experiments to solve scientific problems, controlling the variables in the experiment is crucial to keep the other variable(s) constant and change only one variable under investigation across conditions. Additionally, even if a student can control variables scientifically, it does not mean that the student can design the entire experiment rigorously. According to the principles of controlling variables and designing experiments, students' responses were classified into four strategies. This study has two variables: "Towel Position" and "Water Level." Table 3 presents the descriptions of four strategies and their corresponding response actions.

Table 3
Descriptions of Four Strategies

Strategies	Descriptions of Strategies	Corresponding Response Actions	Representative Codes
Scientific and rigorous (SR)	Able to scientifically control variables and design rigorous experiments	(1) Be able to keep the variable "Towel Position" constant and collect five sets of "Water Level" data, and at least two sets of "Towel Position" can be controlled	[1, 0], [1, 1], [1, 2], [1, 3], [1, 4]; [2, 0], [2, 1], [2, 2], [2, 3], [2, 4]
		(2) Be able to keep the variable "Water Level" constant and collect three sets of "Towel Position" data, and at least two sets of "Water Level" can be controlled	[0, 0], [1, 0], [2, 0]; [0, 1], [1, 1], [2, 1]
Scientific and less rigorous (SLR)	Able to scientifically control variables and design less rigorous experiments	(1) Be able to keep the variable "Towel Position" constant and collect five sets of "Water Level" data, but only one "Towel Position" can be controlled	[2, 0], [2, 1], [2, 2], [2, 3], [2, 4]
		(2) Be able to keep the variable "Water Level" constant and collect three sets of "Towel Position" data, but only one "Water Level" can be controlled	[0, 0], [1, 0], [2, 0]
Incomplete (IN)	Able to control variables but design incomplete and nonrigorous experiments	(1) Be able to keep the variable "Towel Position" constant, but collect incomplete data (only four or three sets of "Water Level" data)	[1, 1], [1, 2], [1, 3], [1, 4]
		(2) Be able to keep the variable "Water Level" constant, but collect incomplete data (only two sets of "Towel Position" data)	[0, 2], [1, 2]
Chaotic (CH)	Unable to control variables and design chaotic experiments	Unable to control variables, and collect data chaotically and irregularly	[1, 2], [0, 0], [2, 1]

To validate the classification, students' total scores received on the assessment and on the HF item for each strategy group were compared. The results for total scores in Table 4 show that the students who adopted the SR strategy received the highest scores. In contrast, the students who used the CH strategy received the lowest scores, suggesting that the total scores declined with the emergence of the nonrigorousness of the experimental design when solving scientific problems. Additionally, for the SR strategy, the maximum value of total scores was 49.00, while the maximum value for the CH strategy was 34.00. Similar trends were found for scores on HF items. The students who applied the SR strategy got the highest scores on the HF item, while the ones who adopted the CH strategy received the lowest scores. Furthermore, the maximum value of scores on the HF item for the SR strategy was 20.00, while the CH strategy had the highest value of 16.00.

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Table 4
Descriptive Statistics of Total Scores and Scores on HF Items across Strategy Groups

Measure	Scientific and Rigorous		Scientific and Less Rigorous		Incomplete		Chaotic	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Total Scores	23.79	10.24	19.43	10.07	17.17	9.62	10.21	7.03
Scores on HF Item	7.23	4.12	5.86	4.02	5.03	4.13	2.52	2.89

The differences in total scores and scores on HF items across strategy groups were further explored. Results of a one-way ANOVA on total scores showed that the means of the four strategies differed (F (3, 1512) = 124.573, p < .05). Games-Howell was utilized to run post hoc tests because the assumption of homogeneity of variance was violated according to the results of the Levene statistic in this study. Pairwise comparisons of the means using Games-Howell tests indicated four significant comparisons: the mean score for the SR strategy (M = 23.79, SD = 10.24) was significantly (p < .05) larger than that for the SLR strategy (M = 19.43, SD = 10.07); the mean score for the SLR strategy (M = 19.43, SD = 10.07) was significantly (p < .05) larger than that for the IN strategy (M = 17.17, SD = 9.62); the mean score for the IN strategy (M = 17.17, SD = 9.62) was significantly (p < .05) larger than that for the CH strategy (M = 10.21, SD = 7.03); and the mean score for the CH strategy (M = 10.21, SD = 7.03) was significantly (p < .05) smaller than that for the SR strategy (M = 23.79, SD = 10.24). Similarly, results for scores on HF item suggest that the means of the four strategies were unequal according to a one-way ANOVA, F (3, 1512) = 90.213, p < .05. Pairwise comparisons of the means using Games-Howell tests indicated four significant comparisons: the mean score for the SR strategy (M = 7.23, SD = 4.12) was significantly (p < .05) larger than that for the SLR strategy (M = 5.86, SD = 4.02); the mean score for the SLR strategy (M = 5.86, SD = 4.02) was significantly (p < .05) larger than that for the IN strategy (M = 5.03, SD = 4.13); the mean score for the IN strategy (M = 5.03, SD = 4.13) was significantly (p < .05) larger than that for the CH strategy (M =2.52, SD = 2.89); and the mean score for the CH strategy (M = 2.52, SD = 2.89) was significantly (p < .05) smaller than that for the SR strategy (M = 7.23, SD = 4.12). These results suggest that the total scores and scores on HF items were significantly different across strategy groups, implying that the classification of strategies can be confirmed experimentally. The strategies adopted when exploring and solving problems could predict problem-solving performance.

Regarding the percentage of each strategy group in this study, the results showed that 18.5% of the problem solvers adopted the SR strategy. A total of 25.4% of the students applied the SLR strategy, and 31.5% adopted the IN strategy. A total of 24.6% of the students designed experiments chaotically and irregularly. Since the SR strategy is a more efficient way to solve scientific problems than other strategies, approximately 81.5% of eleventh-grade problem solvers need to improve their ability to design scientific and rigorous experiments to successfully solve scientific problems.

Detailed Trajectory of Each Experimental Design Strategy

The heatmaps of response actions reflecting the ways the students designed experiments and applied scientific knowledge were analyzed. The horizontal coordinate of the heatmap represents "Towel Position," and the vertical coordinate represents "Water Level." The numbers in each grid in the heatmaps represent the number of clicks on each experimental combination. As shown in Figure 2, according to the shades of color in the graphics, the students who applied the SR strategy mainly focused on controlling variables "Towel Position 2", "Towel Position 1" and "No Towel", and especially collecting the data of combination of "Towel Position 2" and "Water Level 4", suggesting that they cared about all key variables when designing experiments and were more curious about the combination of "Towel Position 2, Water Level 4" for lowering temperature; the students who adopted the SLR strategy paid more attention to control variable "Towel Position 2", and especially collecting the data of combinations of "Towel Position 2, Water Level 4", and "Towel Position 2, Water Level 2", implying that they might have believed "Towel Position 2" could play a better role in decreasing temperature than other towel positions and cared about the roles of "Water Level 4" and "Water Level 2"; the students who used the IN strategy mainly focused on controlling variables "Towel Position 1" and "Towel Position 2", collecting experimental data of combinations of "Towel

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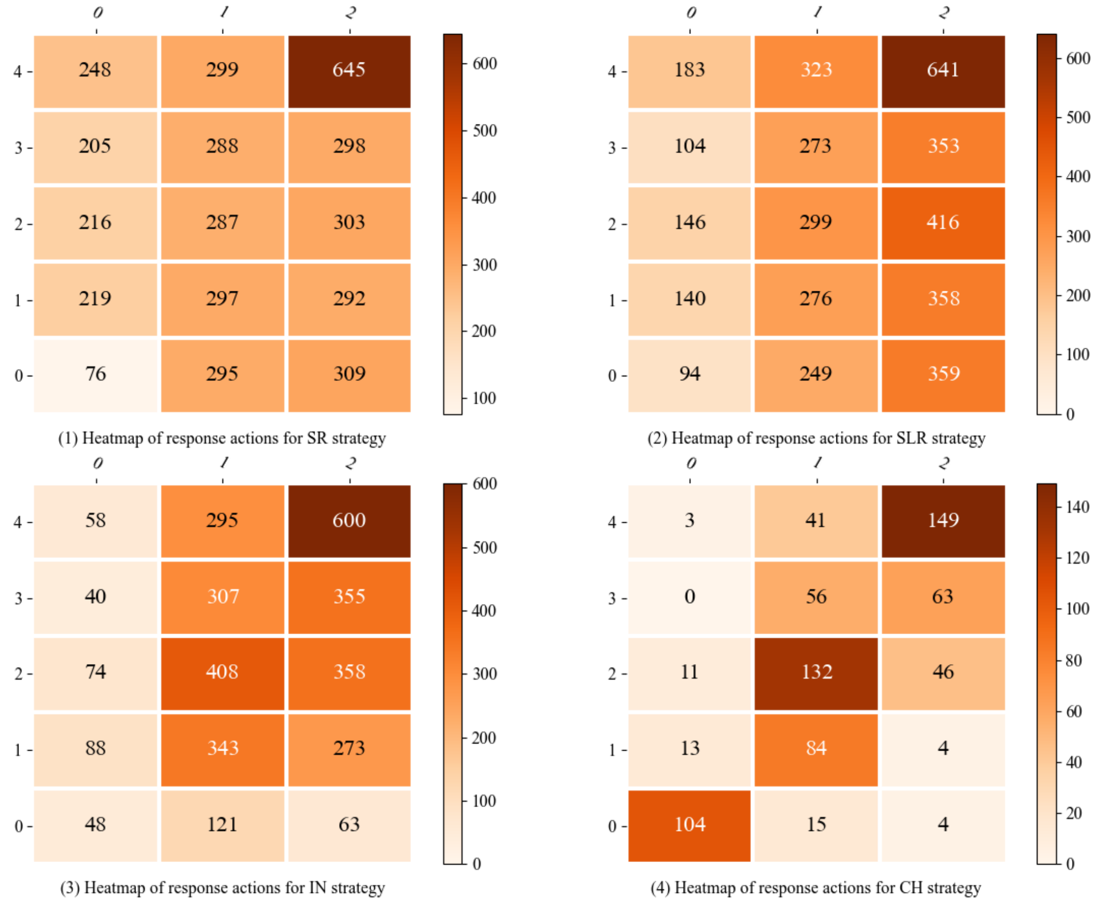
Position 2, Water Level 4", "Towel Position 1, Water Level 2", and "Towel Position 2, Water Level 2", and ignored the data of "Water Level 0" compared to the SR and SLR strategies, suggesting an incomplete and ambiguous experimental design; the students who adopted the CH strategy paid attention to the combinations of "Towel Position 2, Water Level 4", "Towel Position 1, Water Level 2", and "No Towel, Water Level 0", while the design of experiments was completely discontinuous and chaotic.

Figure 2
Heatmaps of Response Actions for the Strategy Groups



Additionally, to further explore the concrete and detailed trajectories of experimental design for solving scientific problems for each strategy group, the top two most representative response action sequences for each strategy were recorded. Table 5 presents the top two most representative response action sequences and the frequency, proportion and examples of these sequences within each strategy group. Due to the various operations in the task for problem solvers, there were 140 sorts of response sequences among 280 students for the SR strategy, 338 kinds of response sequences among 385 students for the SLR strategy, 409 kinds of response sequences among 478 students for the IN strategy, and 125 sorts of response sequences among 373 students for the CH strategy.

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Table 5
Top Two Most Representative Response Sequences Across Strategy Groups and Their Frequency and Proportion Within Each Strategy Group

Strategies	Representative Response Action Sequences	Frequency	Percentage (%)	Examples
Scientific and Rigorous (SR)	…‘[0, 0]’, ‘[0, 1]’, ‘[0, 2]’, ‘[0, 3]’, ‘[0, 4]’, ‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 0]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’…	79	28.2	[‘[0, 0]’, ‘[0, 1]’, ‘[0, 2]’, ‘[0, 3]’, ‘[0, 4]’, ‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 0]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 2]’]
				[‘[0, 0]’, ‘[0, 1]’, ‘[0, 2]’, ‘[0, 3]’, ‘[0, 4]’, ‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 0]’, ‘[2, 2]’, ‘[2, 1]’, ‘[2, 3]’, ‘[2, 4]’]
	…‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 0]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’…	72	25.7	[‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 0]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’]
				[‘[0, 1]’, ‘[0, 2]’, ‘[0, 3]’, ‘[0, 4]’, ‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 0]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’]
Scientific and Less Rigorous (SLR)	…‘[2, 0]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’…	78	20.3	[‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 0]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’]
				[‘[0, 0]’, ‘[0, 0]’, ‘[0, 1]’, ‘[0, 3]’, ‘[0, 4]’, ‘[1, 4]’, ‘[2, 4]’, ‘[2, 4]’, ‘[0, 4]’, ‘[0, 4]’, ‘[2, 0]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’, ‘[1, 4]’, ‘[1, 2]’, ‘[1, 1]’, ‘[1, 0]’]
	…‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’…	52	13.5	[‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’]
				[‘[0, 0]’, ‘[1, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 4]’, ‘[2, 3]’, ‘[2, 3]’, ‘[2, 3]’]
Incomplete (IN)	…‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’…	82	17.2	[‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’]
				[‘[0, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 1]’, ‘[2, 2]’, ‘[2, 3]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’]
	…‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’…	48	10.0	[‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[2, 4]’]
				[‘[0, 0]’, ‘[0, 0]’, ‘[1, 1]’, ‘[1, 2]’, ‘[1, 3]’, ‘[1, 4]’, ‘[1, 4]’, ‘[2, 1]’, ‘[2, 2]’]
Chaotic (CH)	…‘[1, 2]’…	94	25.2	[‘[1, 0]’, ‘[1, 2]’, ‘[1, 2]’, ‘[1, 2]’]
				[‘[1, 2]’, ‘[1, 2]’, ‘[1, 2]’]
	…‘[2, 4]’…	81	21.7	[‘[0, 0]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’]
				[‘[1, 1]’, ‘[2, 2]’, ‘[2, 4]’, ‘[2, 4]’, ‘[2, 4]’]

First, among the students who applied the SR strategy, the most representative sequence was exhibited by 28.2% of the students and involved keeping the variable "Towel Position" (including No Towel, Towel Position 1, Towel Position 2, all three positions) constant and collecting five sets of "Water Level" data for each towel position. Another representative response sequence for the students who adopted the SR strategy involved keeping the variable "Towel Position" (including Towel Position 1 and Towel Position 2, two of the three positions) constant and collecting five sets of "Water Level" data for each towel position.

Second, among the students who used the SLR strategy, the most representative sequence presented in Table 5 involved keeping the variable "Towel Position" (including Towel Position 2 or Towel Position 1, only one of the three positions) constant and collecting five sets of "Water Level" data for each towel position. It is worth mentioning that the proportion of students who exhibited the actions of keeping the variable "Towel Position 2" constant and collecting five sets of "Water Level" data was more than that of the students who kept the variable "Towel Position 1" constant, which is consistent with the results of the heatmap of response actions.

Third, among the students who adopted the IN strategy, the most representative sequence exhibited by 17.2% of the students showed that although they were aware of keeping the variable "Towel Position" (including Towel Position 1 and Towel Position 2, two of the three positions) constant, they collected incomplete "Water Level" data

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for each towel position. Another representative response sequence exhibited by 10.0% of the students involved keeping the variable "Towel Position" (including Towel Position 1, one of the three positions) constant but collecting incomplete data on "Water Level."

Last, for the CH strategy group, the top two representative sequences were exhibited by 25.2% and 21.7% of the students, respectively, suggesting that the students paid attention to the experimental combinations of "Towel Position 1, Water Level 2" and "Towel Position 2, Water Level 4". The findings are consistent with the results of the heatmap of response actions. The CH strategy group cannot design experiments to solve problems based on the principles of controlling variables. This group had no idea how to design experiments and merely solved problems irregularly and chaotically.

Differences in Response Time across Experimental Design Strategies

Table 6 shows that the students who adopted the SR strategy spent the most time-solving problems. In contrast, the students who used the CH strategy spent the least time responding to tasks, suggesting that the students who applied rigorous and scientific strategies needed more time to solve scientific problems.

Table 6

Descriptive Statistics of Total Response and Execution Time Across Strategy Groups

Measure	Scientific and Rigorous		Scientific and Less Rigorous		Incomplete		Chaotic	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Total response time (seconds)	532.26	309.46	428.85	270.13	348.09	273.64	231.78	228.54
Execution time (seconds)	71.66	46.12	59.75	50.02	41.98	34.07	21.04	34.01

Regarding the total response time, the results suggest that the means of response time for the four strategy groups were unequal according to a one-way ANOVA, F (3, 1471) = 71.603, $p < .05$. Pairwise comparisons of the means using Games-Howell tests indicated four significant comparisons: the mean time for the SR strategy (M = 532.26, SD = 309.46) was significantly ($p < .05$) longer than that for the SLR strategy (M = 428.85, SD = 270.13); the mean time for the SLR strategy (M = 428.85, SD = 270.13) was significantly ($p < .05$) longer than that for the IN strategy (M = 348.09, SD = 273.64); the mean time for the IN strategy (M = 348.09, SD = 273.64) was significantly ($p < .05$) longer than that for the CH strategy (M = 231.78, SD = 228.54); and the mean time for the CH strategy (M = 231.78, SD = 228.54) was significantly ($p < .05$) shorter than that for the SR strategy (M = 532.26, SD = 309.46).

Similar trends were found for the execution time. The results suggest that the means of execution time for the four strategy groups were unequal according to a one-way ANOVA, F (3, 1388) = 89.486, $p < .05$. Pairwise comparisons of the means using Games-Howell tests indicated four significant comparisons: the mean time for the SR strategy (M = 71.66, SD = 46.12) was significantly ($p < .05$) longer than that for the SLR strategy (M = 59.75, SD = 50.02); the mean time for the SLR strategy (M = 59.75, SD = 50.02) was significantly ($p < .05$) longer than that for the IN strategy (M = 41.98, SD = 34.07); the mean time for the IN strategy (M = 41.98, SD = 34.07) was significantly ($p < .05$) longer than that for the CH strategy (M = 21.04, SD = 34.01); and the mean time for the CH strategy (M = 21.04, SD = 34.01) was significantly ($p < .05$) shorter than that for the SR strategy (M = 71.66, SD = 46.12).

Discussion

Different Ways of Designing Experiments and Applying Scientific Knowledge Across Strategy Groups

The trajectories of the four strategies in this study reflected various ways of designing experiments and applying scientific knowledge when solving scientific problems. Regarding the ways of designing experiments, the SR group that achieved the highest total scores paid attention to all variables and knew how to scientifically control variables and

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design rigorous experiments to explore the best conditions for lowering the temperature. The SLR group was also aware of controlling variables scientifically and mainly paid attention to the variables they cared about; therefore, the design of experiments was not rigorous and systematic enough. The IN group knew the variables needed to be controlled when designing experiments, while the experimental data for exploring the best condition for lowering temperature were not valid enough because the design of experiments was incomplete and nonrigorous. The CH group, which is also a low-performing group according to their total score, was not aware of controlling variables when designing experiments and designed experiments in a completely chaotic and irregular way. To explore the condition for the best refrigeration effect, students need to combine various variable conditions ("Towel Position" and "Water Level") to set up experimental combinations for comparison. The process of setting up experimental combinations requires a good deal of cognitive resources for controlling variables and designing experiments. The need for abundant cognitive resources to design experiments is consistent with the literature (Gong et al., 2020). The patterns of designing experiments to solve complex scientific problems suggested that successful problem solvers were generally inclined to explore all possible experimental combinations and design experiments scientifically and rigorously.

Regarding the application of scientific knowledge, the SR group paid more attention to the combination of "Towel Position 2, Water Level 4", and the SLR group cared more about the combinations of "Towel Position 2, Water Level 4" and "Towel Position 2, Water Level 2". Therefore, understanding the roles of water levels 2 and 4 was crucial for the students to design experiments. Water level 2 is related to the principle of evaporation and heat absorption. The towel absorbs water in the pot, and then the water evaporates and absorbs heat from the bowl. The process of evaporation and heat absorption plays a vital role in the refrigeration effect. Water level 4 is relevant to another scientific principle that heat transfer occurs when the water in the pot submerges the bowl. Due to heat transfer, water submerging in the bowl would transfer the heat of the water to the bowl to reduce the refrigeration effect. Understanding the aforementioned principles is useful for students to design experiments. The findings showed that many attempts were made to explore what would happen when water submerges the bowl (water level 4) and does not submerge the bowl (water level 2). The SR group students made many more attempts to discover the roles of water level 4 than level 2, implying that the SR group might be aware of the scientific principle of evaporation and heat absorption but not heat transfer. In contrast, the SLR group cared about water levels 4 and 2, suggesting that the SLR group might be confused about the principle of evaporation and heat absorption and the principle of heat transfer. The results indicated that the relevant scientific knowledge and principles in students' minds might affect the use of strategies and the ways they design experiments when solving scientific problems. Successful problem solvers have systematic and structured knowledge, while unsuccessful problem solvers tend to have less scientific and unorganized knowledge (Zajchowski & Martin, 1993). Our findings are consistent with some research showing that conceptual knowledge is basic for students to solve scientific problems and is a predictor of problem-solving competency (Friege & Lind, 2006).

Sufficient Time for Solving Complicated Scientific Problems

Results show that the students who used more scientific and rigorous strategies spent more time seeking solutions when solving scientific problems. Since the scientific problems that occur in scenario-based tasks and daily life are generally complicated and authentic, successful problem solvers usually need to spend more time making plans and finding solutions to better solve the problems in the processes of dealing with difficulties (Cowie, 2015; Gong et al., 2020). The previous findings are consistent with the total response time and execution time results for different strategy groups in this study. That means that to design a scientific and rigorous experiment to successfully solve a scientific problem, ample time might be used to reach the goal. When solving problems, while both successful and unsuccessful problem solvers consider a given problem situation in terms of the problem's objectives, successful problem solvers tend to spend sufficient time making assumptions and mapping the problem situation to an appropriate theoretical model by retrieving valid representations obtained from their larger and better-organized knowledge base (Yerushalmi & Eylon, 2015). Moreover, successful problem solvers may also spend more time than unsuccessful problem solvers reflecting on their former decisions and revising their choices accordingly (Yerushalmi & Eylon, 2015; Jiang et al., 2021).

An explanation for the relationships between time on task and task success may be provided by dual processing theory, which suggests a dynamic interaction of automatic and controlled mental processing (Schneider & Chein, 2003). Automatic processes that are fast do not require active control, whereas controlled processes that last longer than automatic processes require attentional control. Researchers argue that response time on a task is dependent on the relative degree of automatic versus controlled processing required by the task (Goldhammer et al., 2014). Due to the complex processes of problem solving containing knowledge acquisition and the application of this knowledge to

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generate solutions, scientific problem solving must rely on controlled processing to a substantial degree, especially in some difficult tasks. Previous research has indicated that task difficulty affects the relationship between time on task and task success (Goldhammer et al., 2014). It can be assumed that easy tasks require essentially automatic processing to complete, whereas difficult tasks require a higher level of controlled processing. Although successful problem solvers proceed more quickly from information identification to integration, they need to invest sufficient time in seeking solutions rather than in low-level information processing. Accordingly, time spent on problem-solving tasks may increase with task difficulty.

Conclusions and Implications

The purpose of the present study was to explore the eleventh-grade Chinese students' problem-solving strategies and the differences among strategy groups by analyzing process data including sequences of students' response actions and response time. Results showed that students mainly adopted four strategies for designing experiments to solve complicated scientific problems. Successful problem solvers were generally inclined to explore all possibilities of experimental combinations and design experiments scientifically and rigorously based on the relevant scientific principles. There were significant differences in the response time used for solving problems among different strategy groups. The students who adopted more scientific and rigorous strategies spent more time designing plans and seeking solutions to solve complex scientific problems.

The results enrich the literature on using process data obtained from interactive items to address theoretical issues in educational assessment and provide actionable feedback for teaching and learning the skills required in scientific problem-solving tasks. First, students need to be guided and instructed to be aware of the principles of designing controlled experiments when solving scientific problems. Second, students' understanding of the principle of evaporation and heat absorption affected how they designed experiments to solve problems. Science teachers should help students construct a systematic and organized knowledge structure. Third, science teachers should give students sufficient time and ample opportunities to adequately participate in problem-solving activities and make elaborate plans for seeking solutions to cultivate students' scientific problem-solving ability. The length of time for carrying out problem-solving activities should be based on the students' academic performance (e.g., length of time to fully design and complete the experiment) and the difficulty of the tasks.

One limitation of this study is that the conclusions might not be applicable to all Chinese students since the data were collected from students in southern China through a convenience sampling technique with a limited number of sample students. Considerably more research should be conducted to discover patterns of students' problem-solving strategies in a large-scale assessment in other economic or cultural contexts. Additionally, more general conclusions about science could not be reached in this study since the analysis was performed only on one subtask isolated from the set of 17 subtasks in total and the subtask merely belonged to the domain of Physics. More subtasks covering all science-related domains should be analyzed in the future to complement and enrich the findings on students' problem-solving strategies. Moreover, the classification of strategies for solving scientific problems was mainly based on the analysis of process data reflecting students' response actions. In a follow-up study, it would be helpful to further explore the specific descriptions of each strategy group using qualitative analysis, such as think-aloud protocol analysis and interviews.

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Declaration of Interest

The authors declare no competing interest.

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